Canadian Journal of Research

Issued by THE NATIONAL RESEARCH COUNCIL OF CANADA

VOL. 26, SEC. F. OCTOBER, 1948 NUMBER 10

A 600 KV. ION ACCELERATOR[1]

BY J. V. JELLEY[2] AND E. B. PAUL[3]

Abstract

The 600 kv. ion acceleration equipment that has been developed at the Ottawa Laboratory of the National Research Council is described. Details of ion source, power column, and control gear are given. Using hydrogen a total ion beam of 250 to 300 μa. was obtained, of which about 80% was atomic ions.

Introduction

In 1944 it was decided to modify the 600 kv. X-ray set in the Ottawa Laboratory of the National Research Council so that it could be used to accelerate positive ions. The equipment was originally built by Dr. G. C. Laurence in 1937 as a source of 600 kv. X-rays for radiographic and therapeutic dosage standardization, and consisted of a voltage-doubling circuit supplying a negative potential of 600 kv. to an accelerating tube, which contained the electron gun and the X-ray target.

High Tension Generator

The voltage doubler is a three-stage circuit of the Cockcroft–Walton type, generating a d-c. voltage approximately six times the peak voltage supplied by the transformer and supplying a maximum current of 5 ma. Six General Electric type KR-5 Kenotrons rated at 200 kv. inverse peak are used, and the filaments are heated by a series of insulating transformers in cascade, the primary of each being fed from the secondary of the previous one. The main 100 kv. transformer is supplied with 0 to 220 v. at 480 c.p.s. from a motor-generator set, the primary voltage being controlled by varying the field current of the alternator with rheostats. The capacities are built up of 0.02 μf. sections. The total capacity across the output is 0.005 μf. The voltage ripple therefore was about 3 kv. per ma. The rectifiers were reversed to change from negative to positive potential.

Accelerating Tube

The three-stage accelerating tube is built up of glass cylinders, 28 in. long, 14 in. in diameter, and $\frac{1}{4}$ in. thick, separated by steel disks that support the

[1] *Manuscript received May 27, 1948.*

Contribution from the National Research Council of Canada. Issued as N.R.C. No. 1814.

[2] *Physicist, United Kingdom Staff at the Montreal Laboratory of the National Research Council of Canada. Present address: Cavendish Laboratory, Cambridge, England.*

[3] *Physicist, National Research Laboratory, Ottawa, Ontario. Present address: Chalk River Laboratory, Chalk River, Ontario.*

electrodes. The whole is mounted vertically on a steel pumping manifold supported in a steel framework. The joints between the glass cylinders and the steel disks are sealed with Apiezon Q compound. The steel disks are cut away to increase the pumping speed in the upper parts of the tube, and the edges are shielded by corona rings both inside and outside the glass. The coaxial accelerating electrodes and the ion source are connected to the 200, 400, and 600 kv. points on the H.T. set by 500,000 ohm resistors. The brass electrodes are 4 in. in diameter and are chromium plated to reduce sputtering on the glass walls.

The tube was initially evacuated by two Metrovac oil diffusion pumps, types 04B and 02 in series, backed by two Hypervac-20 mechanical pumps in parallel, which gave a pumping speed of approximately 150 liters per sec. of air at 10^{-5} mm. of mercury. Later, in order to be able to enlarge the pumping canal in the ion source, a DPMC-500 oil-diffusion pump was substituted for the 04B pump, and this arrangement increased the pumping speed to approximately 500 liters per sec. A liquid-air trap is built into the pumping manifold near the mouth of the main diffusion pump in order to exclude oil vapor from the main accelerating tube.

The pressure in the main tube is measured continuously in the range 10^{-4} to 10^{-5} mm. of mercury by a gauge of the Philips type (6), and the fore-vacuum pressure between the 02 diffusion pump and the backing pumps is read by a thermocouple gauge. The pressure at the latter point is about 5 μ, and the thermocouple gauge has sufficient sensitivity in this range.

The target tube is attached underneath the steel manifold supporting the accelerating tube. The target chamber may be isolated from the main vacuum system by a bronze vacuum-tap consisting of a large tapered straight-through stopcock with a $1\frac{1}{2}$ in. hole through which the ion beam can pass. The small end of the rotating cone of the stopcock is surrounded by a chamber connected to the main vacuum system so that the two parts of the stopcock are pressed tightly together by air pressure in either the open or closed position.

Power Column and Ion Source

Electrical power for the ion source is required at the high potential end of the tube. This is supplied by an alternator driven by an insulating belt from a motor at ground potential. The general layout of the power column is shown in Figs. 1 and 2. The stack consists of a Dilecto cylinder, $7\frac{1}{2}$ ft. long, 3 ft. in diameter, and $\frac{1}{4}$ in. thick, mounted on a steel framework and supporting a plywood electrode, approximately 5 ft. in diameter and $\frac{1}{8}$ in. thick. This electrode was fabricated* in one piece by building up the plywood on a wooden form and then baking the glue in a large oven. The electrical components are mounted on a steel framework which rested on a floor within the electrode. The electrode is painted with a "Dag" preparation consisting of colloidal graphite suspended in an organic solvent.

* *This construction was carried out in the Structures Laboratory of the National Research Council.*

Mounted inside the electrode are a 2 kva. alternator driven by a rubber V-belt from a 5 h.p. motor at floor level, a 30 kv. full wave rectifying set with four 0.01 μf. condensers in parallel, which supplies 30 ma. d.c. for the discharge tube, the control gear for the set, and for the heater of the palladium

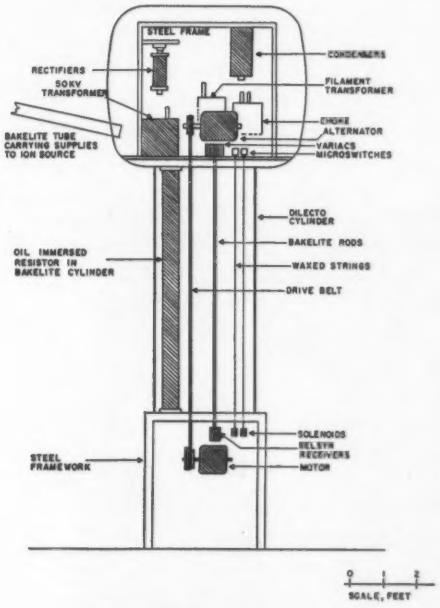

FIG. 1. *Sketch of the power column.*

tube that admits hydrogen or deuterium to the discharge tube. This leak was mounted directly on the ion source inside an aluminum spinning at the top of the accelerating tube and is of all-metal construction. The leak (designed by Dr. H. M. Cave) consisted of two palladium thimbles hard-soldered inside a steel envelope. The hydrogen line to this leak from the hydrogen supply at the base of the power stack, as well as the electrical supplies from the power stack, are taken from the power column electrode to the ion source through a bakelite tube.

A sketch of the ion source as finally used is shown in Fig. 3. The operation of this type of source has been described by Oliphant and Rutherford (5) and others (2, 3). The ring of metal inside the porcelain insulator keeps the minimum distance between the electrodes less than the mean free path of the electrons in the gas at the working pressure of the discharge tube.This precaution reduces the possibility of breakdown at this point. It also shields the porcelain surface, since a breakdown across this surface generally produces a semiconducting path along which breakdowns would occur more and more

frequently. The centering of the inner electrode is very critical and has to be correct to about 0.001 in.

The final design of the cathode block of the ion source was adopted after trials of other designs. The first model ended in a toroidal steel block with

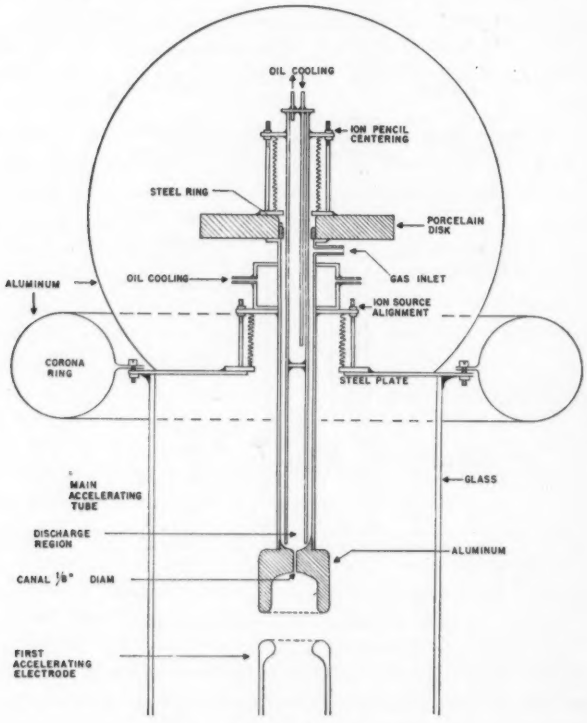

FIG. 3. *Sketch of the ion source.*

the lower end of the canal less than $\frac{1}{2}$ in. from the surface of the "lens." The toroid was about 1 in. smaller diameter than the electrode that it faced. With this arrangement a considerable part of the ions emerging from the canal were lost after undergoing the first acceleration. The later model (designed by Dr. H. M. Cave) was intended to allow the ions to emerge first into a relatively field-free region and then to be focused by a symmetrical "lens." This served to focus a larger part of the output of the ion source and resulted in a narrower beam and a higher beam current at the target. The diameter of the beam at the target was approximately 0.5 cm. Aluminum is used for the end surface of the ion source to reduce the X-rays produced at this point by secondary electrons accelerated up the tube. The pumping canal shown is that used with the 500 liters per sec. pumping system; with the lower pumping speed a canal half the diameter was used. The ion source is

PLATE I

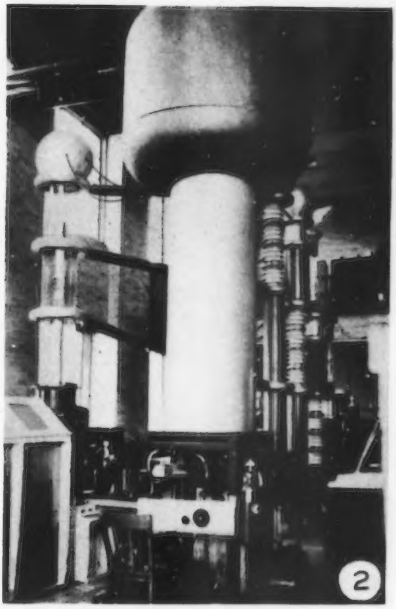

FIG. 2. *Photograph of the ion accelerator, with the power column in the foreground.*

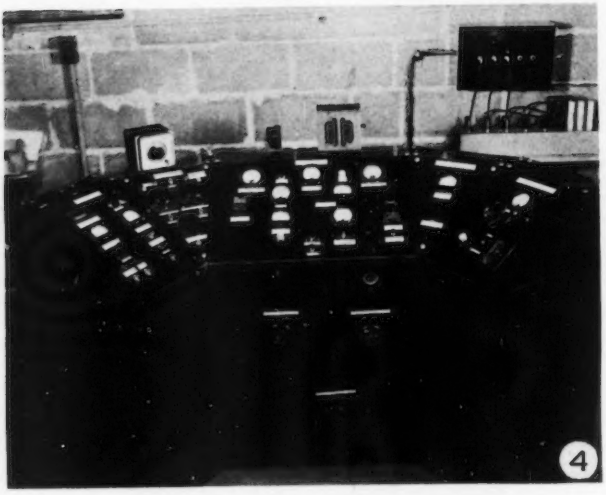

FIG. 4. *Photograph of the control desk of the ion accelerator.*

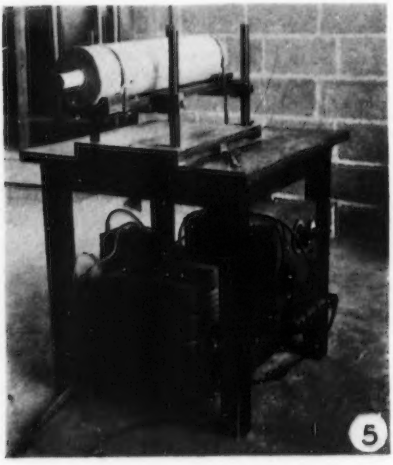

FIG. 5. *Photograph of the neutron monitor.*

cooled by transformer oil continuously circulated from the ground level through bakelite and neoprene tubes; the oil itself was cooled at ground level in a tank by a copper spiral through which water circulated.

The main accelerating potential is measured by a 7 ft. resistor mounted inside the power column stack. It was constructed of about 500 two-megohm standard ceramic sealed 1 w. carbon resistors arranged in a helix around a bakelite cylinder of diameter 2 in. This was mounted inside a 4 in. Dilecto cylinder filled with transformer oil. This oil was at first circulated. However this was found to be unnecessary as a coolant and the simpler arrangement of static oil as an insulator was adopted. The voltage across 1/3000 of the main resistor is measured by a bridge method in which this small fraction of the total voltage is balanced against a similar voltage from a power supply. The method has the advantage that an accurate robust meter can be used. The voltage-measuring equipment was calibrated by means of the γ-ray resonances from protons on lithium and fluorine.

Controls

Whenever the accelerated beam of ions strikes part of the accelerating tube, secondary electrons are liberated and accelerated up the tube. These give rise to X-rays on striking the ion source and other metal parts within the tube. The dosage received around the base of the tube and power stack was found to be several hundred times the tolerance dose per day. This made it necessary to place all controls behind a 13 in. cement wall about 50 ft. from the accelerating tube.

All controls are mounted on a desk-shaped panel, which is shown in Fig. 4. The controls on the 30 kv. set and the palladium tube leak heater in the power-stack electrode are turned directly through 8 ft. bakelite shafts by Selsyn motors (General Electric Type 2JD5H1) driven from corresponding motors mounted behind the control desk.

If the current through the Philips gauge exceeds a certain value (i.e., the pressure exceeds a certain value) it lowers the bias on a valve that actuates a relay that turns off the high voltage.

Monitoring Equipment

One purpose of the equipment was to provide strong sources of neutrons from the (d, n) type of reaction. A monitoring system was therefore desired that would give a continuous reading of the fast neutron flux during an experiment. For this facility a long, thin-walled copper counter filled with boron trifluoride gas was employed and was operated in the proportional region so that it was insensitive to relatively high γ-ray backgrounds that might be present. This type of neutron monitor has been described by Hanson and McKibben (4), who have found the sensitivity of their instrument to be reasonably constant for neutrons of energy between 10 kev. and 5 Mev. They quote a result by R. F. Taschek that indicates a falling-off in sensitivity

by 60% at 16 Mev. The counter that we used was of length 24 in. and diameter 0.5 in. and was mounted along the axis of a paraffin-wax cylinder of diameter 6 in. and length 24 in., the whole being sheathed in a cadmium skin to exclude slow neutrons scattered from nearby objects. The monitor was mounted on an adjustable holder attached to a table (see Fig. 5) and could be "aimed" at the target. The table also carried the electrical equipment which consisted of stabilized power supplies, filter unit, amplifier and a circuit for integrating the pulse rate. This provided a d-c. output proportional to the neutron flux, which was displayed on a meter on the control desk so that relative values of the flux level could be recorded during experiments. The pulse-rate integrating circuit is shown in Fig. 6.

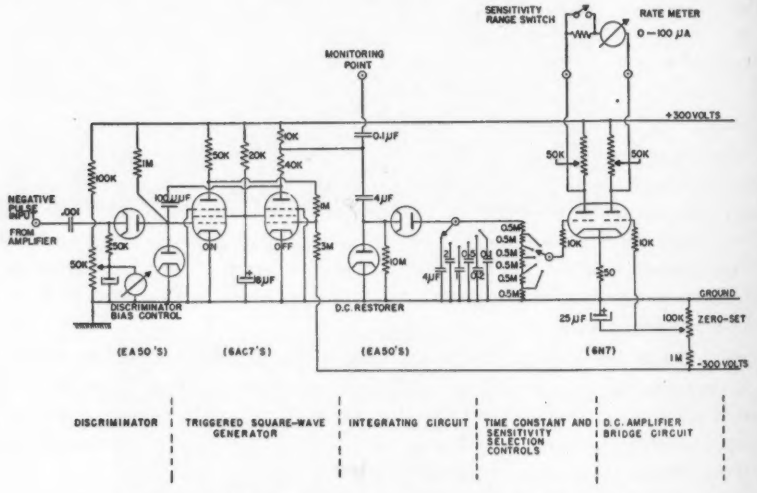

FIG. 6. *Circuit diagram of the pulse-rate integrating meter.*

The equipment can also provide a strong source of γ-rays from (p, γ) reactions; these were monitored by a suitable Geiger–Müller counter, the output pulses being supplied to the rate-meter circuit as for the neutrons. The counter, placed close to the target, was heavily shielded by lead to reduce to a minimum the background counts produced by X-rays from the set.

Owing to the unsafe X-ray intensities present in the main room, all recording apparatus such as scaling units and oscilloscopes had to be in the control room. The effective cable-lengths between the detecting devices (ion chambers, counters, etc.) at the target and the control room being 50 ft., it was necessary to supply electrical units for satisfactory distortion-free transmission of pulses from the apparatus near the target to the recording equipment. Each unit, one situated near the target and one at the control desk, is provided with five channels for carrying five independent connections if necessary. Each

channel of the "transmitter" unit contains a phase inverter and a cathode-follower so that pulses of either sign can be introduced and transmitted at low level down the respective cable. Each channel of the "receiver" unit contains one tube operated as a phase-splitter so that pulses of either sign can be made available to the recording gear.

Performance

With the small pumping canal in the ion source running on hydrogen the total current on the target was from 80 to 100 μa. A rough magnetic analysis at the target showed that about 80% of the ion beam was atomic, in agreement with the early observations on this type of source (5). When the canal was enlarged to $\frac{1}{8}$ in. diameter the total current was increased to 250 to 300 μa. Voltage stability was around 1%. However, the inhomogeneity of ion energy was much greater since an ion source of this type produces ions with a total spread of about 25 kv. The neutron intensities produced by bombarding various targets with 600 kv. deuterons and comparing the count in the neutron monitor with that produced by a Ra–Be source are as follows:

$D_2O + P_2O_5$ target	250 mc. equivalent per μa.
Be metal target	600 mc. " " "
Li metal target	500 mc. " " "

The yields for beryllium and $D_2O + P_2O_5$ targets are in agreement with the yields found by Amaldi, Hafstad, and Tuve (1), but our measured yield for lithium is about 40% lower, which difference may be due to the decreased sensitivity of our neutron monitor at high neutron energies.

The γ-ray yield from a lithium metal target bombarded by the unresolved beam of 600 kv. protons was measured by a calibrated "thick-walled" ionization chamber and was found to be of the order of 10^{-2} mc. per μa.

Acknowledgments

This work was done in the British–Canadian Atomic Energy Project under Dr. J. D. Cockcroft, and was initially under the immediate direction of Dr. W. E. Burcham and, after September 1945, of Dr. H. M. Cave. The valuable help of Mr. J. W. McKay and the excellent technical assistance of Mr. P. S. Lamb are gratefully acknowledged.

References

1. Amaldi, E., Hafstad, L. R., and Tuve, M. A. Phys. Rev. 51 : 896-912. 1937.
2. Bouwers, A., Heyn, F. A., and Kuntke, A. Physica, 4 : 153-159. 1937.
3. Craggs, J. D. Proc. Phys. Soc. London, 54 : 245-265. 1942.
4. Hanson, A. O. and McKibben, J. L. Phys. Rev. 72 : 673-677. 1947.
5. Oliphant, M. L. E. and Rutherford, Lord. Proc. Roy. Soc. London, A, 141 : 259-281. 1933.
6. Penning, F. M. Physica, 4 : 71-75. 1937.

THE OXIDATION, IGNITION, AND DETONATION OF FUEL VAPORS AND GASES

VII. THE OXIDATION OF PENTANE IN VARYING CONCENTRATION IN AIR AT TEMPERATURES RISING TO 700° C. AND THE EFFECT OF IRON CARBONYL ON REACTION VELOCITY[1]

By R. O. King[2]

Abstract

Results are given for the oxidation in reaction chamber No. 10 of pentane mixed with air, mixture strength being varied from 25% weak to 100% rich. Oxidations were carried out with and without additions of iron carbonyl to the pentane. The experiments were made mainly to find a rational explanation for the antiknock property of rich fuel–air mixtures. The experimental results for undoped mixtures show that, at temperatures approaching those of the end gas in an engine, reaction velocity increases by 100% on increasing mixture strength over the range mentioned above and by 100% on increasing temperature from 600° to 650° C. Similar increases in reaction velocity with rise of temperature and with increase of mixture strength were obtained for the doped mixtures over the high temperature range but at temperatures 150° C. lower than for undoped mixtures. The characteristics of the experimental results confirm the conclusion reached in earlier Parts, namely, that oxidation of pentane in the conditions of the experiments is a heterogeneous reaction.

Introduction

It has been shown by experiments already described (1, 2, 3) that oxidations of pentane and hexane can be carried out in reaction chamber No. 10, without explosion, at whatever temperature may be required for completion of reaction. The experiments, with one exception, were made when using mixtures of combining proportions with air. Their oxidation characteristics are described in the references quoted and experimental evidence given showing that detonation in an engine is delayed or prevented by dilution of the end gas with oxidation products (3).

The liability of a fuel–air mixture to detonate varies with mixture strength, and the experiments to be described in this Part were made to determine the oxidation characteristics of weak and rich mixtures, in particular to ascertain the fundamental reason for the antiknock property of rich mixtures which is of importance in practice.

Experimental Arrangements

The No. 10 reaction chamber used for the experiments was of Jena Supramax glass and of the dimensions given in Part I (1). Pentane, taken as before, as a representative liquid paraffin hydrocarbon was used to form mixtures with air in varying proportions. The pentane and the methods of measurement were as described in the appendix to Part I.

[1] *Manuscript received May 28, 1948.*
Contribution from Defence Research Board, Ottawa, Canada.

[2] *Research Scientist, Naval Division, Defence Research Board, lately Director of Scientific Research and Development, Royal Canadian Navy.*

The rate of air supply to the reaction chamber in cubic centimeters per minute was measured at room temperature and the pentane added as liquid in conditions ensuring that vaporization was complete before the mixture entered the chamber.

A pentane–air mixture is defined as being weak or rich according to the percentage by which the pentane constituent is less or greater than that required for combining proportions.

Thus,—

Combining proportions mixture is	$C_5H_{12} + 8\ O_2 + 30.3\ N_2$
100% rich mixture is	$2C_5H_{12} + 8\ O_2 + 30.3\ N_2$
25% weak mixture is	$0.75C_5H_{12} + 8\ O_2 + 30.3\ N_2$

A combining proportions mixture of pentane with air would, according to kinetic theory, contain 2.87% only of pentane vapor. Rates of mixture supply given in the text are to be taken as rates of air supply plus whatever addition of pentane vapor is required for the stated mixture strength.

Rates of oxygen reacted as given by the graphs are for pentane–air mixtures; the proportion of nitrogen is omitted from the stated composition.

Percentage concentrations of iron carbonyl stated in the text are in respect of the pentane constituent of the pentane–air mixture, the carbonyl being added as liquid to the pentane prior to vaporization.

Temperatures of reaction are taken as indicated by the "inside" thermocouple resting on the top of the reaction chamber (1, pp. 333-334).

Experimental Results

Flow configuration is the major factor determining rate of oxidation (2) and in reaction chamber No. 10 may be such that reaction is so rapid at some temperatures that measurement of rate is difficult. The configuration in the chamber is fixed by rate of mixture supply and the diameter of the admission orifice; factors which determine degree of turbulence and the velocity with which the reacting mixture impinges on the active surface. If the rate of mixture supply is too small and the diameter of the orifice too large, the velocity of the jet may not be sufficient to ensure deposition of metal rather than of metallic oxide on the surface of the chamber when the mixture contains a metallic dope such as iron carbonyl.

On the other hand, if the velocity of the jet is increased sufficiently to ensure deposition of metal on the surface of the chamber, flow configuration conditions arise which increase reaction velocities in rich mixtures to such an extent that measurement may be extremely difficult. The difficulty of choosing a suitable flow configuration is illustrated by the series of experiments described in succeeding paragraphs.

Rates of oxidation observed for the flow configuration due to passing a combining proportions pentane–air mixture through the 1.0 mm. orifice at 50 cc. per min. are given by the graphs of Fig. 1. It will be noted that iron

carbonyl in the concentration of 1.0% *increases rate of reaction at all temperatures*, the aldehyde hump not being eliminated on the addition of the dope, as in earlier experiments. The failure of iron carbonyl to inhibit aldehyde formation was attributed to the jet velocity being insufficient to ensure deposition of metal on the active surface of the reaction chamber, and the velocity

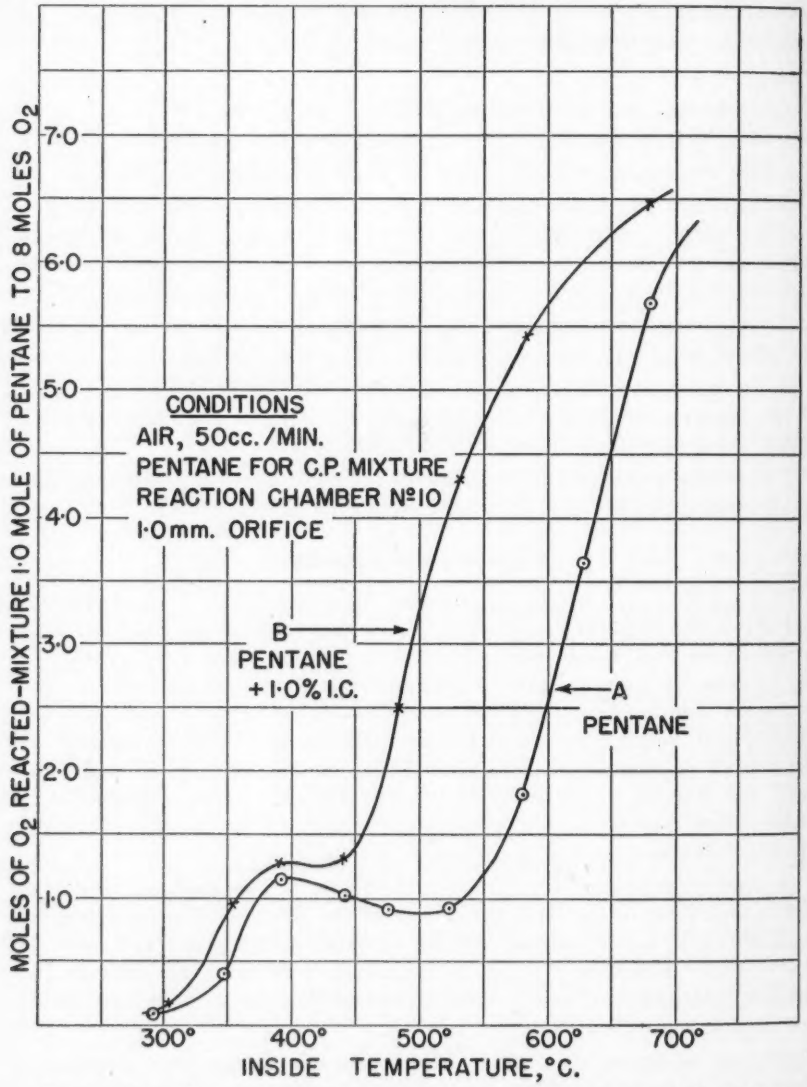

FIG. 1. *Rates of oxygen reacted, pentane and pentane plus iron carbonyl for the flow configuration due to supplying a combining proportions mixture with air at 50 cc. per min.*

was increased by raising the rate of mixture supply to 75 cc. per min. The experimental results then obtained are given by the graphs of Fig. 2. It will be noted, graph *B* of the figure, that the aldehyde hump has disappeared. Comparing graph *B* with the similar graph of Fig. 1, it will be seen that a

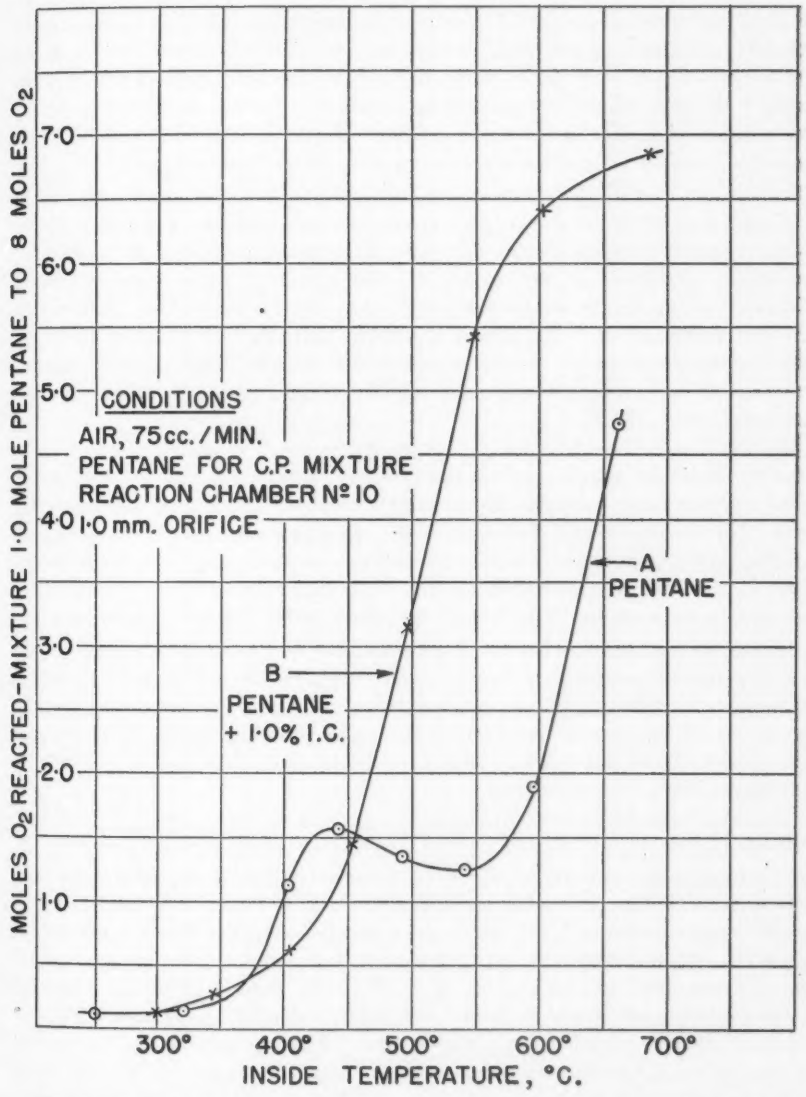

FIG. 2. *Rates of oxygen reacted, pentane and pentane plus iron carbonyl for the flow configuration due to supplying a combining proportions mixture with air at 75 cc. per min.*

higher rate of oxidation at temperatures above 450° C. is obtained on increasing rate of mixture supply of the *doped mixture* from 50 cc. to 75 cc. per min. On the other hand, a comparison of graphs *A* of Figs. 1 and 2 shows that, for *undoped* pentane, rate of oxidation at high temperatures diminished with increase in rate of mixture supply.

The experiments described above indicated that the flow configuration fixed by a mixture supply of 75 cc. per min. was to be preferred to that given by the lower rate of 50 cc. per min. if the characteristic effect of the dope to inhibit aldehyde formation were to be obtained. It then remained to determine rates of oxidation in the conditions if pentane were mixed with air greatly in excess of the proportion required for a "correct" mixture. The results of an experiment made accordingly are given by the graphs of Fig. 3.

Graph *A* of the figure shows that even for pentane undoped, reaction velocity was so great in a 100% rich mixture, over the temperature range 350° to 390° C. and again over the range 600° to 650° C., that observations were not obtained. Graph *B* of the figure obtained when the pentane contained iron carbonyl in the concentration of 1.0% shows a similar high reaction velocity over the high temperature range but at temperatures approximately 150° C. lower, reaction of the oxygen being substantially complete at the relatively low temperature of 550° C.

Rates of formation of carbon oxides are of interest. The graphs of Fig. 5 show that for the doped pentane, rate of formation of carbon monoxide was inappreciable, reaction being substantially to carbon dioxide and steam at any temperature. On the other hand, the graphs of Fig. 4 for pentane undoped show a rapid increase in rate of carbon monoxide formation over the temperature range above 600° C. It was demonstrated by the experiments described that reaction occurred at inconveniently high velocity when 100% rich mixtures were used.

The object of the experiments described above was to fix conditions suitable for experiments in which mixture strength would be the sole variable over the widest practicable range. It was concluded that suitable flow configuration would be set by passing the mixture through a 1.0 mm. orifice at 75 cc. per min. and that reaction velocity might not be too great if a maximum mixture strength of 50% rich were used.

Reaction velocities for a combining proportions mixture obtained when the rate of mixture supply was 75 cc. per min. are given by the graphs of Fig. 2, and the experiments were concluded by oxidations of mixtures 25% weak and 50% rich. The doped combining proportions mixture contained iron carbonyl in the concentration of 1.0% in the pentane, and, in order that the substance might be supplied to the reaction chamber at a constant rate irrespective of mixture strength, concentrations of 1.33% and 0.67% respectively in the pentane were used in the weak and rich mixtures. The experimental results are given by the graphs of Figs. 6 to 9, Nos. 7 and 8 giving rates of formation of the carbon oxides for the weak mixture. Similar graphs for the 50% rich mixture are largely duplicates of those of Figs. 4 and 5 for the 100% rich mixture and are not given.

Discussion of Experimental Results

The preliminary experiment, Fig. 1, made to determine a favorable rate of mixture supply for subsequent measurement of the effect of mixture strength on reaction velocity, discloses that conditions can be obtained in which a metallic

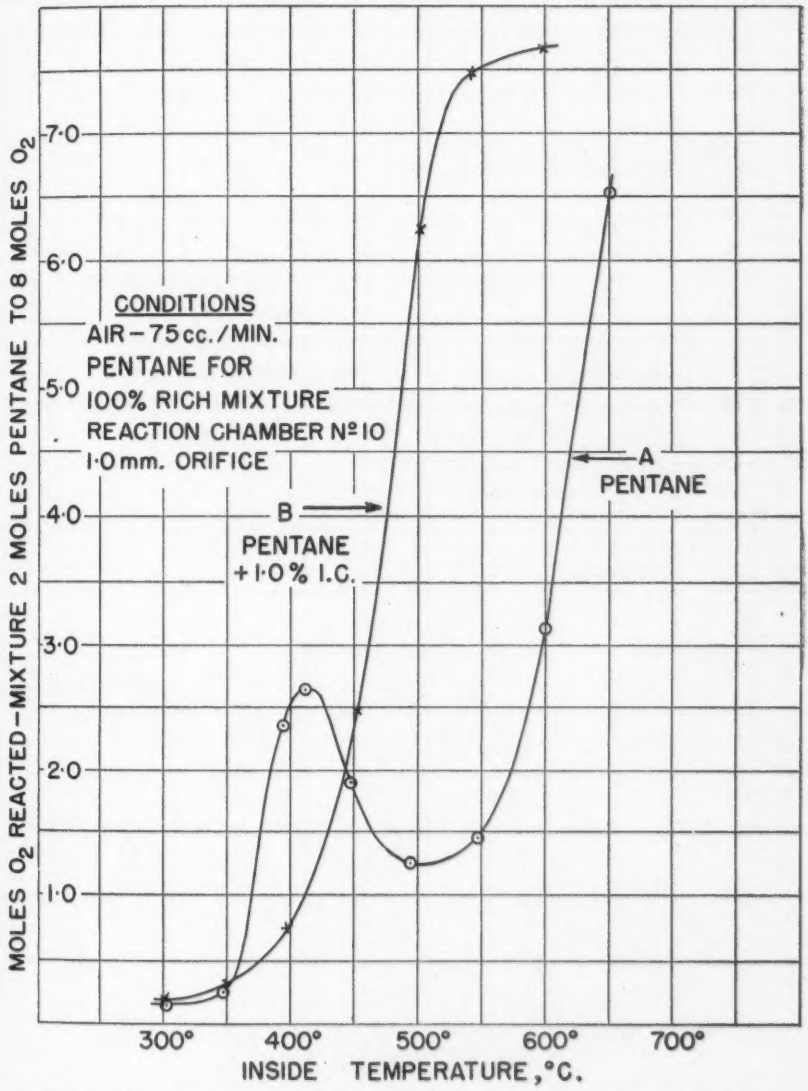

FIG. 3. *Rates of oxygen reacted, 100% rich pentane–air mixture, with and without iron carbonyl, for flow configuration fixed by supplying the mixture at 75 cc. per min.*

dope such as iron carbonyl promotes oxidation at all temperatures of reaction. The flow configuration consequent on supplying reacting mixture to the reaction chamber at an unusually low rate, through a relatively large orifice, was such that with the doped mixture the active surface was mainly coated with iron oxide instead of with metal as found in earlier experiments when

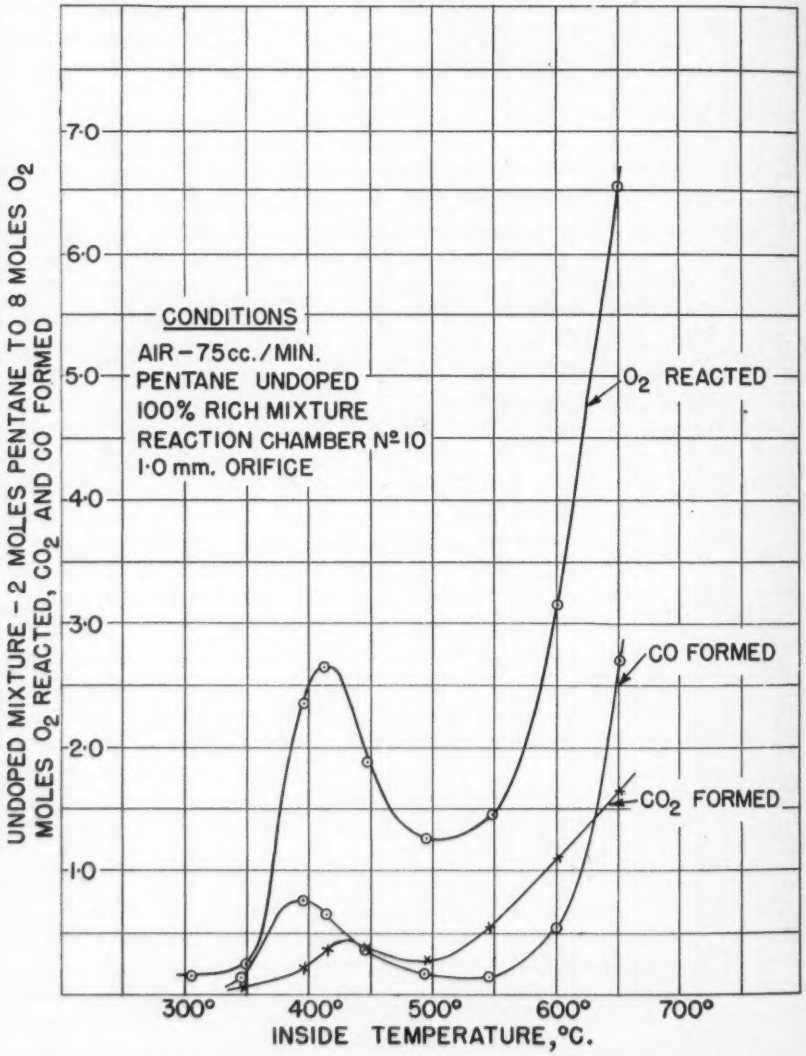

FIG. 4. *Rates of formation of carbon oxides, 100% rich undoped pentane–air mixture supplied at 75 cc. per min.*

using higher rates of mixture supply. The experimental results show that reaction to aldehyde as indicated by the hump on graph *B*, Fig. 1, proceeds at a higher rate on the oxide coated surface than on the clean glass surface, graph *A*, Fig. 1. The experiments show that iron oxide is most active to promote aldehyde formation when freshly formed. Thus referring to Part III

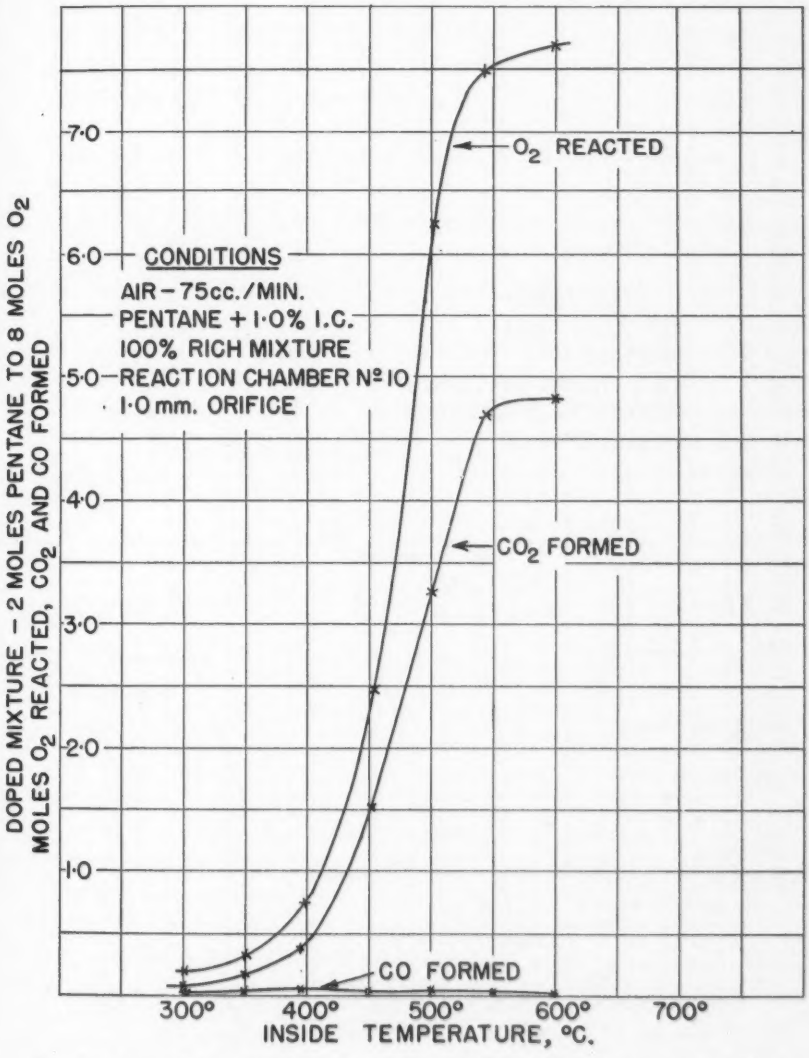

FIG. 5. *Rates of formation of carbon oxides, 100% rich doped pentane–air mixture supplied at 75 cc. per min.*

(3, pp. 130-131) it was shown that although aldehyde instead of final products was formed in reaction chamber No. 10 on converting the metal previously deposited on the active surface gradually to oxide, reaction velocity was less than when the surface was clean glass. On increasing the rate of mixture

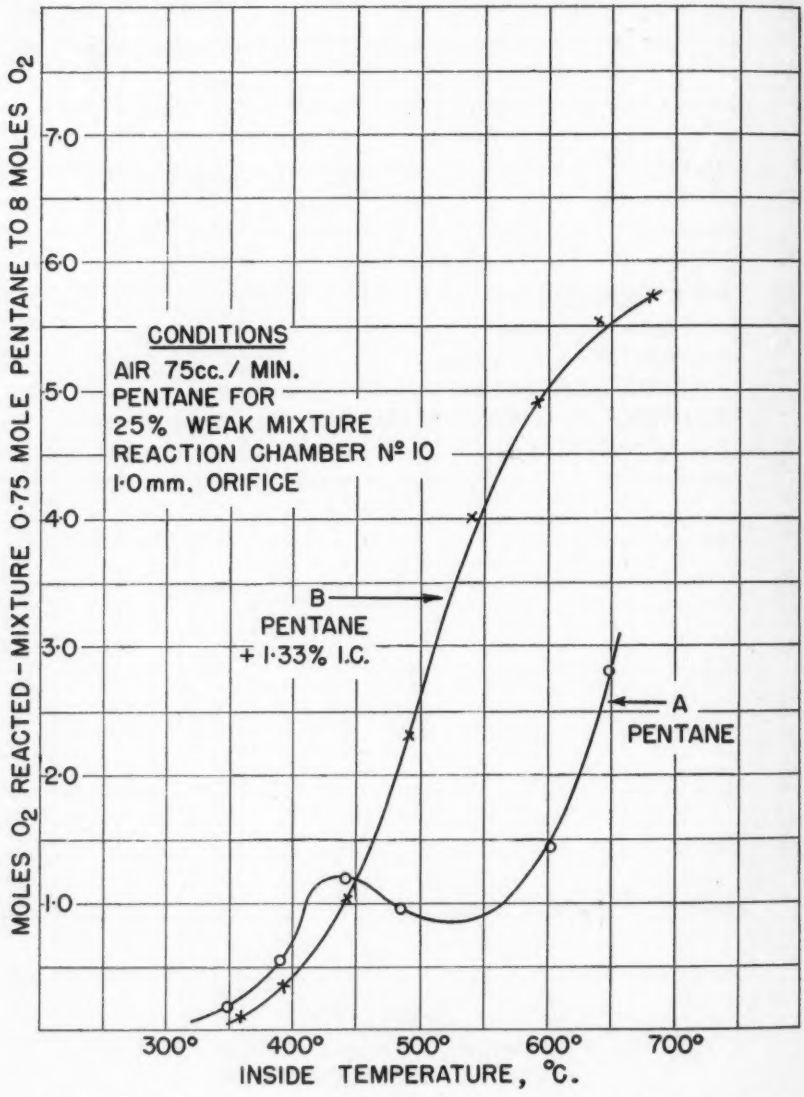

FIG. 6. *Rates of oxygen reacted, 25% weak pentane–air mixture, with and without iron carbonyl, for flow configuration fixed by supplying the mixture at 75 cc. per min.*

supply to 75 cc. per min. and thereby obtaining a deposit of metal on the active surface of the chamber, aldehyde is no longer obtained and reaction is to steam and carbon dioxide only, graph *B*, Fig. 2.

The experimental results, similarly to those given earlier (1, 2, 3), support the view that the low temperature oxidation of pentane and presumably

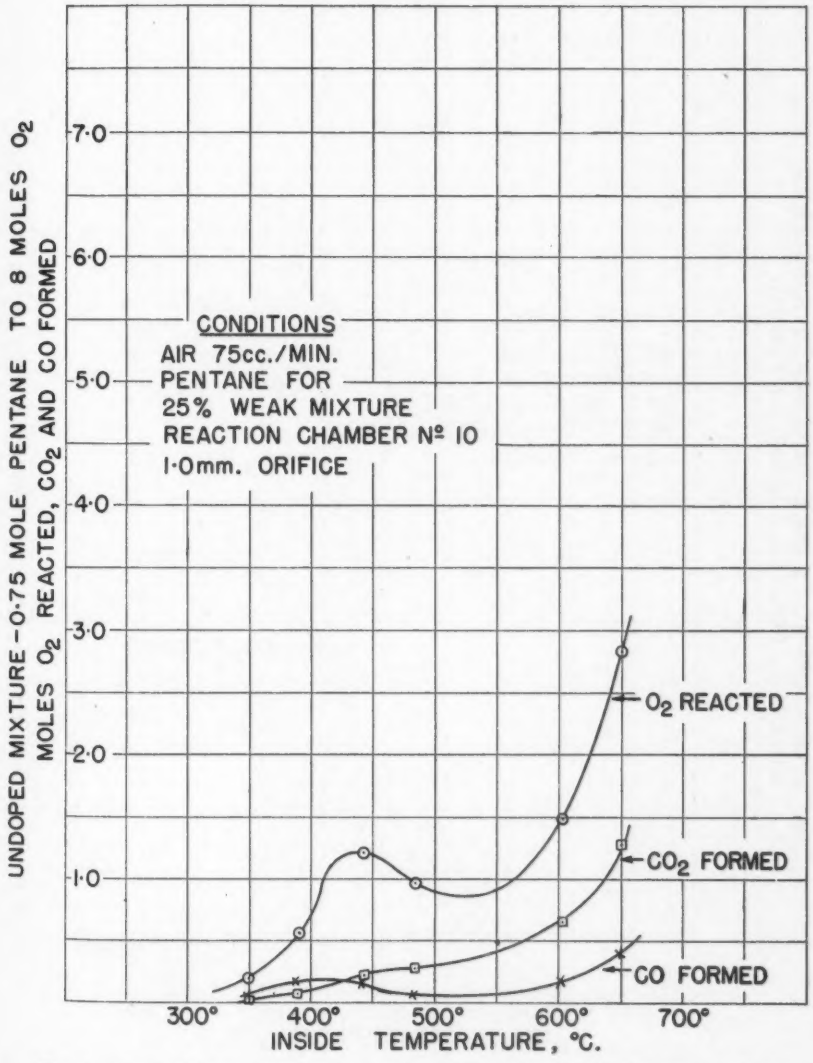

FIG. 7. *Rates of formation of carbon oxides, 25% weak undoped pentane–air mixture supplied at 75 cc. per min.*

similar hydrocarbons is a surface reaction; not one that can be explained by chain reaction theory. It is of interest that many attempts made accordingly have not led to any agreement in respect of the nature of the chain carriers or of the assumed unstable reaction products which are required to maintain the reaction (see review by Ubbelohde (5, pp. 2945-2947)).

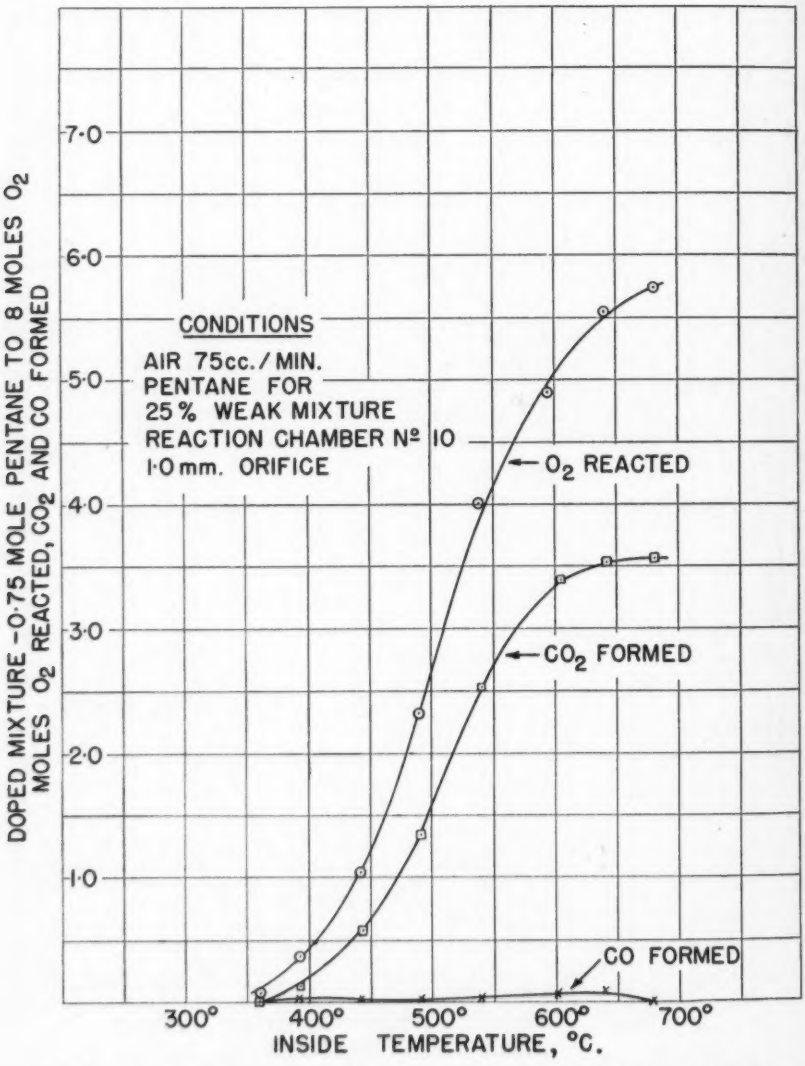

FIG. 8. *Rates of formation of carbon oxides, 25% weak doped pentane-air mixture supplied at 75 cc. per min.*

Mixture Strength and Reaction Velocity, Doped Pentane

Collected graphs showing rates of oxidation in weak, combining proportions and rich doped mixtures are given, Fig. 10. A remarkable increase in reaction velocity on increasing mixture strength is shown by the graphs. Thus,

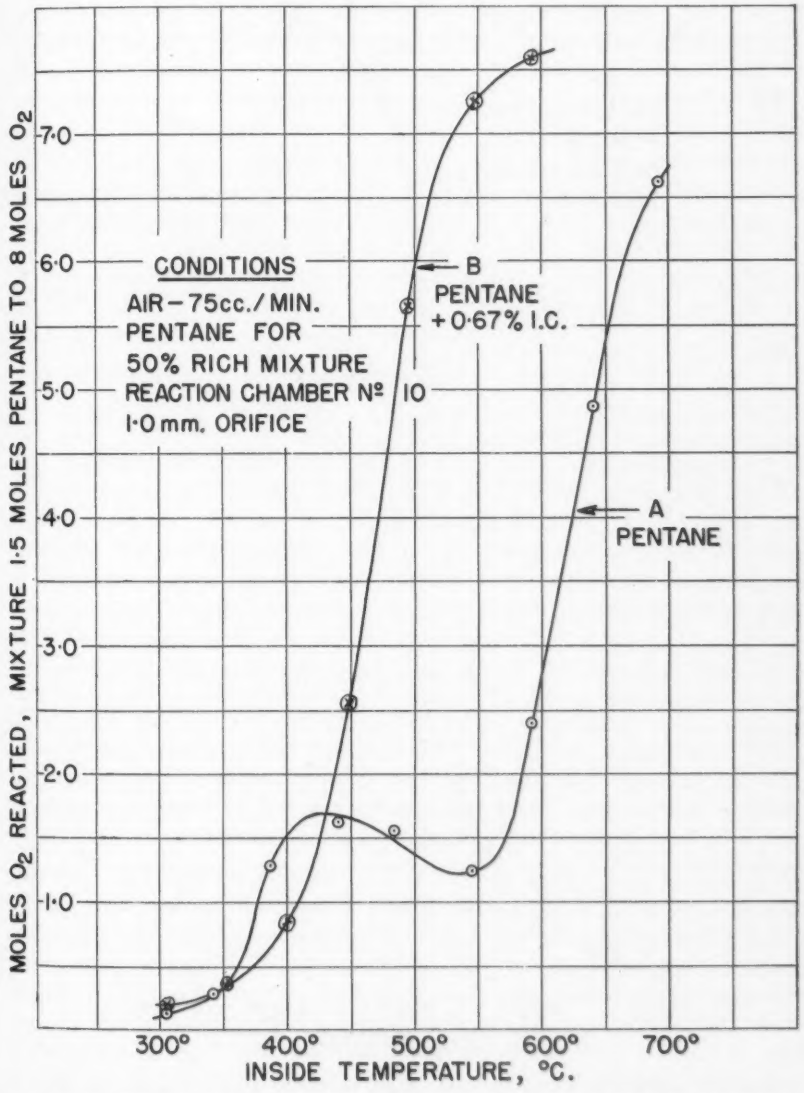

FIG. 9. *Rates of oxygen reacted, 50% rich pentane–air mixture, with and without iron carbonyl for flow configuration fixed by supplying the mixture at 75 cc. per min.*

substantially all the oxygen in the rich mixtures was reacted at 550° C. to form steam and carbon dioxide, graph 1, whereas in the 25% weak mixture about 5.8 moles only of oxygen out of the 8.0 moles available were reacted

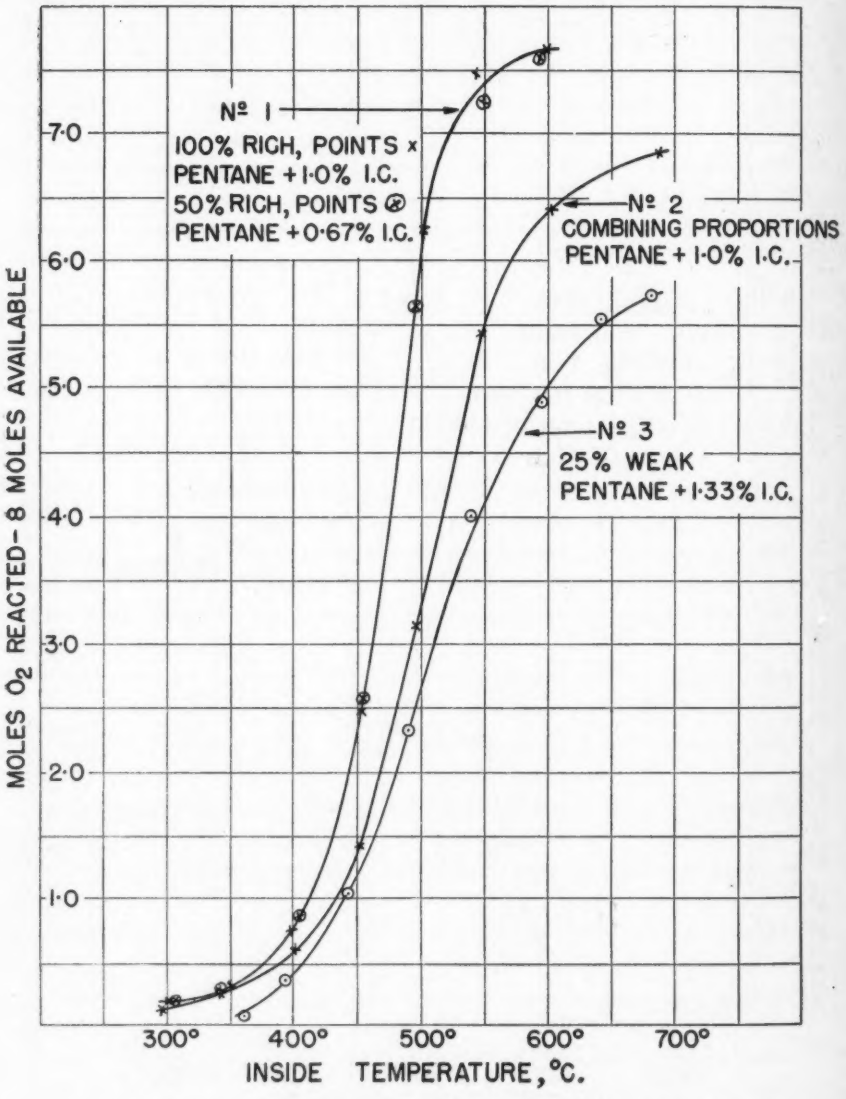

FIG. 10. *Collected graphs showing that oxygen reacted for doped pentane–air mixtures reaches a limiting value, at all temperatures of reaction without explosion on increasing mixture strength and dope concentration.*

even at the relatively high temperature of 690° C. Reaction velocities at low temperature are also of interest. It will be noted, Fig. 10, that reaction began at a measurable rate at about 360° C. in the weak mixture but was easily measurable at 300° C. in the richer mixtures.

Reaction velocities for a particular flow configuration reach limiting values at all temperatures of reaction on increasing mixture strength. Thus a single graph, 1, Fig. 10, can be drawn through the experimental points obtained for the 100% rich mixture containing pentane plus 1% iron carbonyl and the 50% rich mixture containing pentane plus 0.67% of the dope. Reaction in both cases was to final products only, the rate of formation of carbon monoxide being inappreciable. The consequence is that the excess pentane in both cases was not even partially oxidized and there was no visible evidence during the experiments of decomposition. It appears, therefore, that the oxidation reaction took possession of the surface, and in the circumstances there was little if any decomposition of the pentane vapor at the temperatures of the experiments. It may be, therefore, that the *decomposition* of pentane is a heterogeneous reaction at least at temperatures below 700° C.

Mixture Strength and Reaction Velocity, Undoped Pentane

The course of the reaction when pentane only is oxidized in reaction chamber No. 10 is characterized by the rate of formation of carbon monoxide for any mixture strength reaching a maximum within the temperature range 400° to 450° C. and again over the temperature range beginning at 600° C. The carbon monoxide over the low temperature range doubtless derives in large part from the oxidation of the aldehyde which is formed at a rate increasing with increase of mixture strength. Reaction velocity would not, therefore, be expected to reach a limiting value until the mixture contained pentane and oxygen in equimolecular proportions.

Reaction velocity at temperatures above 600° C. is also characterized by an increase in rate of formation of carbon monoxide as mixture strength increases, Figs. 5 and 7, but aldehyde does not appear in the products of the reaction. Velocity appears to approach a limiting value as mixture strength is increased, and the experimental results indicate that it might be attained by using mixtures more than 100% rich in pentane and obtaining equilibrium in respect of the reaction products, namely, steam and the carbon oxides.

Nature of the Oxidation Reaction

It has already been mentioned that in the experimental conditions, which are similar to those prevailing in an engine, the oxidation of pentane over the temperature range of aldehyde formation appears to be a heterogeneous reaction. The experiments also indicate that oxidation at high temperature is a reaction of the same sort. Thus the pentane vapor can be exposed to any temperature up to 700° C. while reaction proceeds with high velocity to reach a limiting value, without the occurrence of ignition or explosion. Such effects could not be obtained if the reaction were homogeneous.

Oxidation of the End Gas in an Engine as Affected by Mixture Strength

The temperature attained by the end gas varies with many conditions of engine operation but in usual circumstances temperatures are estimated to rise from about 670° to 880° C. as the compression ratio is increased from 4 to 10 : 1 if taken when combustion is 90% complete, Part IV (4, p. 233). The high temperature range of the experiments described in this part may be taken as from 600° to 650° C. although in one set of experiments nearly 700° C. was reached. Although the engine end gas temperatures are the higher, the time of exposure of the mixture in the engine is shorter than in the reaction chamber, so oxidation characteristics may be taken as similar to those found in the reaction chamber at lower temperatures. Undoped pentane being considered, relevant data taken from the *A* graphs of Figs. 2, 3, 6, and 9 are set out in Table I below.

TABLE I

MOLES OXYGEN REACTED (8 MOLES AVAILABLE) UNDOPED PENTANE

Temperature, ° C.	Mixture proportion, pentane–air			
	25% Weak	Correct	50% Rich	100% Rich
600	1.5	2.0	2.8	3.1
650	3.0	4.2	5.4	6.5
700	—	—	6.7	—

It will be seen by reference to the table that irrespective of mixture strength an increase in rate of oxygen reacted of approximately 100% is obtained on increasing the temperature from 600° to 650° C. A further effect of especial significance in respect of detonation in the engine is that the proportion of the available oxygen reacted also increases by approximately 100% over the range of mixture strength given in the table, at either 600° or 650° C.

Acknowledgments

The experimental work described in this paper is part only of that carried out in the Colloid Science Laboratory, Cambridge University, with the co-operation of Prof. E. K. Rideal and Dr. F. H. Garner and the assistance of Mr. R. R. Davidson, Emmanuel College.

References

1. KING, R. O. Can. J. Research, F, 25 : 326-342. 1947.
2. KING, R. O. Can. J. Research, F, 26 : 36-56. 1948.
3. KING, R. O. Can. J. Research, F, 26 : 125-150. 1948.
4. KING, R. O. Can. J. Research, F, 26 : 228-240. 1948.
5. UBBELOHDE, A. R. *In* The Science of Petroleum, Vol. 4. Edited by A. E. Dunstan, Oxford University Press, London, New York, Toronto. 1938.

AN ULTRAVIOLET PHOTOMETER[1]

By R. B. Harvey[2]

Abstract

A photometer for use in the near ultraviolet has been designed and built with particular attention to simplicity, ruggedness, and reliability.

The construction of a photometer involves two problems—

1. The provision of a light source of the desired wave length and of constant intensity, and
2. The measurement of the change of property, usually intensity, of the light when it is passed through the substance to be investigated.

The provision of a constant light source of the correct wave length has been dealt with in several ways. Ballard and Thornton (1) used a 4 w. germicidal lamp, a large proportion of the radiation of which is of wave length 2537 Å. The germicidal lamp is fairly satisfactory as a source of 2537 Å as it emits little heat and it operates on 110 v. a.c. with standard accessories. Hanson (2) and Klotz (3) have used low wattage bulbs, but they introduced a constant voltage transformer and an inductance-capacitance network to stabilize the lamp. Silverman (5) wished to work at wave lengths slightly longer than 3000 Å and used an AH-4 lamp (100 w. mercury vapor) and a voltage and current stabilizing network similar to Hanson's. An argon bulb* has also been used to some advantage for work in the near ultraviolet. A sodium arc was used by McFarlan, Reddie, and Merrill (4) for vitamin A analyses at 3303 Å.

With the present instrument the measurement of change of light intensity was accomplished by means of a photocell, a direct current amplifier, and a milliammeter. The photocell** chosen was the RCA 929 with a maximum sensitivity in the region of 3800 Å. The amplifier is conventional. The photocell current flows through a 100 megohm grid resistor to cause a change in grid voltage; the variation of grid voltage is amplified and the resultant anode current change is read on a milliammeter. Ballard and Thornton (1) have a somewhat more elaborate balanced bridge system. Hanson (2), Klotz (3), and Silverman (5) used conventional single tube amplifiers.

The Photometer

In this photometer it was desired to have a machine powered entirely by the a.c. mains, rugged, simple to operate, and reliable over long periods of operation. An argon bulb (2½ w., 110 v. a.c.) was chosen as a light source

[1] *Manuscript received in original form September 12, 1947, and, as revised, July 26, 1948. Contribution from the Defence Research Board, Ottawa, Canada.*

[2] *Major, Defence Research Board.*

* *Paper presented before the American Society of Biological Chemists, March 1938.*

** *Data on phototubes and circuits suitable to them are given in the RCA pamphlet "Phototubes." The basic design of the circuit in this paper was taken from page 10 of this pamphlet, 1940 ed.*

because it emitted little heat and operated directly from the a-c. mains. The amplifier was built with a simple voltage stabilized high tension supply to render it less sensitive to plate supply voltage variations. The instrument was found to operate best with a Sola constant voltage transformer as a source of power.

This photometer was constructed in two parts. The light source – photocell unit was connected to the electrical measuring system by a length of shielded flexible cable which allowed considerable freedom of movement. It was desirable in this case to have the optical end of the instrument mobile, but there is no reason why the complete photometer cannot be built as an integral unit. The optical system consists of a light source ($2\frac{1}{2}$ w. argon glow lamp operating directly on the a-c. supply), a cell for the sample, and a photoelectric cell. The argon bulb was chosen as it gave a fairly good proportion of its radiation in the 3500 to 4000 Å region and because it caused no problem from emitted heat. The samples were contained in standardized test tubes such as are used for colorimetry. The photoelectric cell was a type 929 RCA sensitive in the region of 3800 Å. A diagram of this unit is shown in Fig. 1.

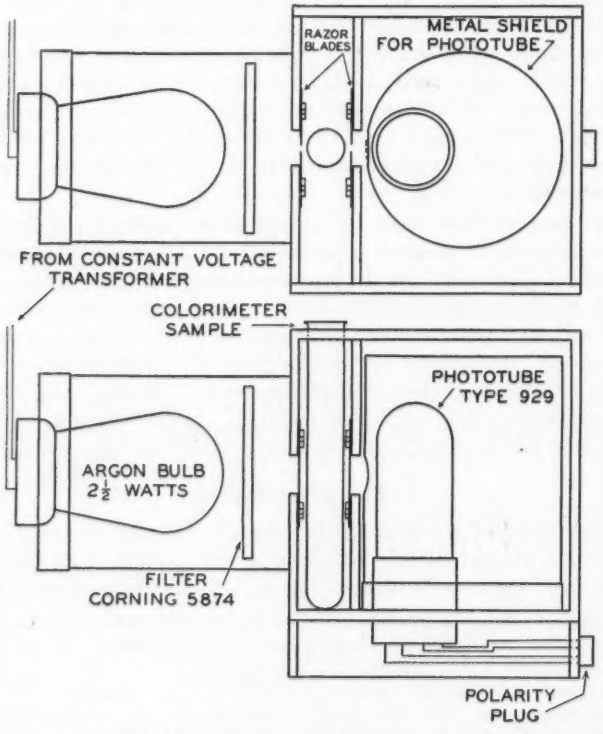

FIG. 1. *Top and side views of mechanical arrangement of parts.*

A two-wire shielded cable was used to connect the photoelectric cell of the optical unit to the amplifying unit. The latter unit, comprising the electrical parts, is shown in two diagrams for simplicity. Fig. 2, *A*, shows the photometer amplifier, Fig. 2, *B*, shows the power supply. The negative side of the high voltage is grounded and the + 75 v. and + 150 v. leads are connected to the amplifier as shown.

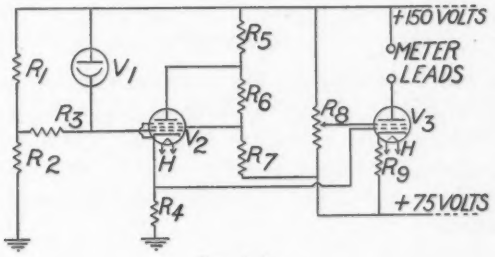

FIG. 2,A.

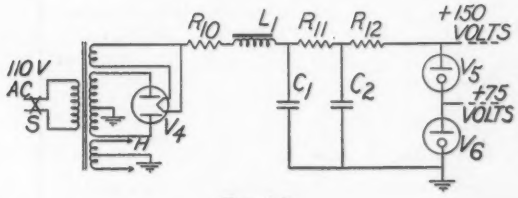

FIG. 2,B.

FIGS. 2,A, AND 2,B. *Power supply circuit and phototube amplifier circuit for photometer.*

R_1, 500,000 ohms, ½ w.
R_2, 330,000 " ½ w.
R_3, 100 megohms precision (glass type).
R_4, 500,000 ohms, 1 w.
R_5, 30,000 " 1 "
R_6, 20,000 " 1 "
R_7, 30,000 " 1 "
R_8, 10,000 " potentiometer.
R_9, 2,000 " 1 w.
R_{10}, 5,000 " 20 "
R_{11}, 3,000 " 10 "
R_{12}, 2,000 " 10 "

C_1 and C_2, 16 mf. 450 working volts.
L_1, 10 h. 50 ma.
V_1, 929 phototube (RCA type).
V_2, 6SK7
V_3, 6V6
V_4, 5W4
V_5 and V_6, VR-75 voltage regulator.

S, Double pole, single throw switch for 110 v. mains.
Meter, 0 – 1 ma.

Consider the amplifier shown in Fig. 2, *A*. Resistors R_1 and R_2 provide a potential across V_1, the photoelectric tube. The values of R_1, R_2, and R_4 are chosen so that the grid potential of V_2 is near that of its cathode. Light falling on the phototube causes a current through the 100 megohm resistor R_3 (causing a positive voltage to appear at the grid end) and the potential so obtained is applied to the V_2 grid. The grid allows more current to flow in V_2 and makes the cathode end of R_4 more positive. This positive potential is applied to V_3 causing an increase of current in V_3 and, consequently, through the meter. The resistor system R_5—R_7 inclusive provides screen and plate voltages for V_2, and R_8 provides a variable screen potential for V_3 and allows

the meter reading to be varied or set at any desired figure. The positive voltages (i.e., + 75 and + 150 v.) are taken from voltage regulating tubes to increase stability.

In Fig. 2, *B*, is shown the power supply. A Hammond type 270B transformer supplies the heater and high tension voltages. Resistors R_{10}, R_{11}, and R_{12} are used to reduce the potentials across the voltage regulating tubes to a safe value.

Operation

Operation is extremely simple. The machine is turned on and allowed to warm up for 10 to 20 min. When the instrument is to be used for ultraviolet colorimetry it is found best to insert a blank and adjust the reading on the meter to full scale. The sample is substituted for the blank, and a second reading taken. From a standard curve the concentration of the sample may be estimated directly.

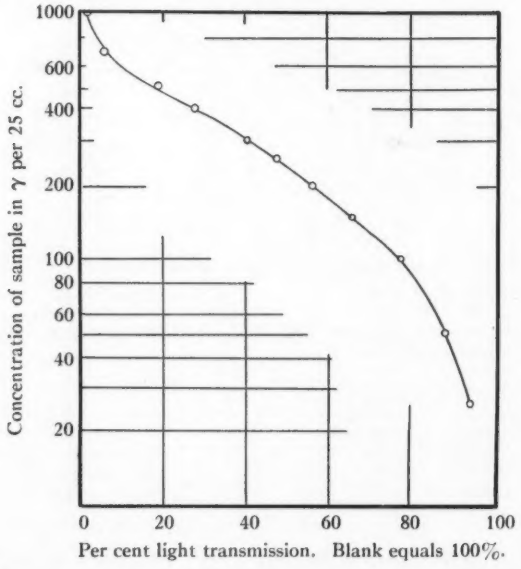

FIG. 3. *Standard curve of concentration versus transmission for a heavy metal analysis.*

In Fig. 3 is shown a typical standard curve for the photometer when it was used for the analysis of a heavy metal. This curve was obtained with a Sola constant voltage transformer delivering 124 v. as a power supply. The most useful fraction of the curve extends from 50 μgm. per sample with transmission 88% of that of the blank to something about 700 μgm. with transmission 7% of that of the blank, although this range may be extended somewhat at both ends with sacrifice of accuracy.

A few experiments were carried out to find the effect of a variation of supply voltage on the transmission readings for a given concentration. The supply voltages were obtained from a "Variac" fed by a constant voltage transformer and the voltage was read on an a-c. voltmeter to 0.1 v. These data are

TABLE I

THE EFFECT OF VARIATION OF SUPPLY VOLTAGE ON THE LIGHT TRANSMISSION OF SEVERAL SAMPLES

Conc., μgm.	Supply volts						
	130	125	120	115	110	105	100
	Transmission readings						
10	98.5	98.5	98	98	98	98.5	98.5
25	97	96.5	95.5	95.5	95.5	96	97
50	90.5	90.5	89	88	88	90	—
150	75	70.5	65	69	71	73	—
250	54	48	47	51.5	54	61	62
500	21	20	19	24.2	32	38	—
1000	1	1	2	4.5	12	18	26
2000	0	0	0	1	4.5	11	17
3500	0	0	0	0.2	3	8	15

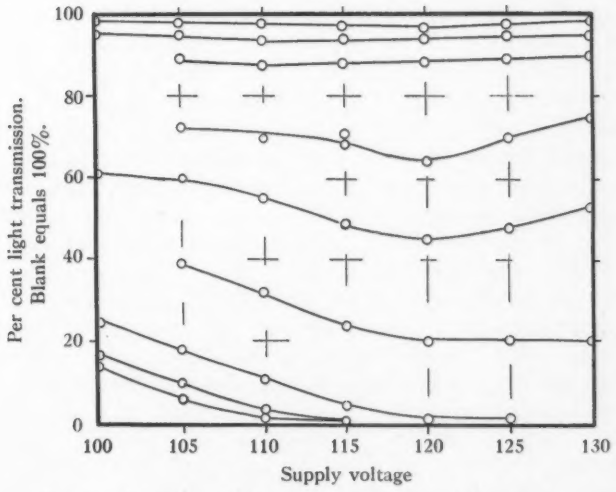

FIG. 4. *Variation of light transmission with supply voltage.*

given in Table I and plotted in Fig. 4. A suitable voltage at which to operate the instrument is probably about 120 to 125 v. as, on the whole, the transmission–voltage curves tend to be flattest in this region.

The best performance of the photometer has been obtained by feeding it with a constant voltage transformer. It has been found in operation that some care in measurements may be necessary in order to get the most from the photometer. Although the sample tubes used for these trials were the so-called colorimeter tubes, it was necessary to match the required number by comparison with one another from a stock of the tubes, as slight flaws were evident in the glass. Care was necessary to put the tube into the colorimeter always in the same way, as rotation of the glass caused fluctuations of the reading. It was found wise to eliminate gas bubbles from the tubes before measurement and each tube was inspected carefully every time it was inserted into the instrument. With these few precautions the reproducibility was as good as the accuracy of the meter readings.

These figures for the light transmission in this table were obtained by setting the blank to 100% transmission at the voltage chosen, measuring the percentage transmission of the sample and, immediately, reinserting the blank to ensure that its transmission remained constant at 100%.

References

1. BALLARD, A. E. and THORNTON, C. D. W. Ind. Eng. Chem., Anal. Ed. 13 : 893-897. 1941.
2. HANSON, V. F. Ind. Eng. Chem., Anal. Ed. 13 : 119-123. 1941.
3. KLOTZ, I. M. Ind. Eng. Chem., Anal. Ed. 15 : 277-278. 1943.
4. MCFARLANE, R. L., REDDIE, J. W., and MERRILL, E. C. Ind. Eng. Chem., Anal. Ed. 9 : 324-326. 1937.
5. SILVERMAN, S. Ind. Eng. Chem., Anal. Ed. 5 : 592-595. 1943.

AN INK-WRITING CARDIOCHRONOGRAPH FOR THE STUDY OF THE ACTIVITY OF THE HUMAN AUTONOMIC NERVOUS SYSTEM[1]

By W. W. Loucks, S. S. Kostashuk, and Alan C. Burton

Abstract

A study of the fluctuations of cardiac period from beat to beat gives information as to the activity of the vagus and sympathetic nerves which control heart rate. The instrument uses the electrocardiac voltages (Q.R.S. complex) between right arm and left leg, with the left arm grounded to the instrument. The out-of-phase voltages are amplified first by a differential amplifier, of high discrimination, then by a two stage pulse amplifier. The output is further amplified and distorted by a 'pulse-shaping' circuit to give a positive-going triggering impulse. This impulse, by 'striking' the thyratron of a 'sweep generator', causes the discharge of a condenser which has been slowly charging at a nearly constant rate. A recording milliammeter, of the ink-writing type, is connected to the condenser through a 'sweep amplifier' so that it draws a series of transverse lines on the record, the length of each being determined by the duration of the cardiac period before the next triggering impulse arrives. Over a long period of time, every successive cardiac period is recorded in a comparatively short record. Results have already shown the astonishing variability of the normal cardiac rhythm.

Introduction

A cardiochronograph (or cardiotachometer) is an instrument that records the instantaneous heart rate, or rather the period of each successive heart beat. The physician, when taking the pulse rate, usually counts the number of beats in 30 sec., or in an even shorter period, and so arrives at an average heart rate for the period of time of his observation. However, the heart rate, like all biological phenomena, has a wide fluctuation, and in the period of observation the "instantaneous rate" (the reciprocal of an individual heart period) may have varied widely from the average rate for the whole period.

The heart contains a "pace-maker," which initiates the rhythmic beats, but the rate is widely modified by two sets of nerves belonging to the autonomic nervous system, namely the cardiac accelerator nerves, part of the "sympathetic" nervous system, which speed the heart rate; and the vagus nerves of the "parasympathetic" system, which slow the heart. A continuous record of the spontaneous changes in heart rate, recorded by the cardiochronograph, will therefore give information as to the spontaneous activity of these nerves. Also, a cardiochronographic record of what happens to the heart rate when stimuli (emotional, drugs, etc.) are given to the subject, will give information as to the activity of the autonomic nervous system under these stimuli. With the increased interest in "psychosomatic medicine," which is concerned with phenomena in which the autonomic nervous system plays a very important role, the cardiochronograph becomes a very useful tool of research. With the growing interest in this field, it seems desirable that the apparatus should be described in some detail.

[1] *Manuscript received May 31, 1948.*

Contribution from the Departments of Physics and of Biophysics, University of Western Ontario, London, Ont.

Historical

The earliest reference known to us is the work of Boas (1) who constructed a "cardiotachometer," which, actuated by the electrocardiographic impulses, indicated on a counter (cyclometer) the number of heart beats in each minute. Independently, Fleisch (2) used the pulsation in volume of peripheral tissues with each heart beat to actuate a "Pulszeitschreiber." In this a pointer rose at a steady rate, drawing a vertical line on a smoked drum, until the cardiac pressure pulse interrupted its motion and it returned to zero, to start its upward motion again after a fixed short interval of time. Thus if the heart period were long, a tall vertical line would be drawn on the record, if the period were short, a short vertical line would be drawn.

The inherent difficulty with the method of Fleisch is due to the use of the peripheral change of volume of a limb with the heart beat to trip the mechanism, for during periods of constriction of the blood vessels, this will greatly decrease in amplitude. Also there is an appreciable lag in the time at which the pulse reaches the periphery, and this lag is not constant, because the "pulse wave velocity" changes with the state of tension of the blood vessels. Thus the changes in heart period would not be accurately recorded where vascular changes were also present. For this reason Whitehorn, Kaufman, and Thomas (4), and later White and Gildea (3) combined the use of the electrocardiographic impulse (the "Q.R.S. complex") to actuate the trigger mechanism with the "Zeitschreiber" principle of Fleisch (with some mechanical modifications).

A cardiotachometer on this principle, but utilizing photographic recording of the horizontal movement of a line of light from a mirror galvanometer (which executed the interrupted "sweeps") on vertically moving bromide paper, was developed by the Aero-Medical Research Unit of the Mayo Clinic, U.S.A.A.F., for use in experiments in acceleration. We are indebted to them for a circuit diagram of their arrangement. The instrument here described differs in design of circuits and in utilizing an ink-writing recording milliammeter. (Easterline-Angus). It is less expensive and more convenient to operate than photographic recording equipment.

General Description

This cardiotachometer consists of an amplifier to amplify the Q.R.S. complex of Lead II (right arm to left leg), a linear-sweep generator, counter circuits for providing calibration pulses, and a moving-paper ink-recorder.

The first stage of the pulse amplification consists of a differential amplifier. Fig. 2 shows a block diagram of the complete unit. Three electrodes are used on the subject. The left-arm connection is grounded. The right-arm and the left-leg electrodes are connected to the two inputs of the differential amplifier. The out-of-phase cardiac voltages which appear across the input of the amplifier are amplified and passed on to the next stage of pulse amplification. The in-phase voltages, due to stray pickup by the body, are rejected

by the amplifier. A balance control allows adjustment of the gain for each electrode so that the in-phase voltages can be cancelled out. An electric-eye indicator is used to give visual indication when the balancing is correct. (Figs. 1, 2, 3, and 4 give the scheme of circuits, the complete circuit diagrams, and mounting details.)

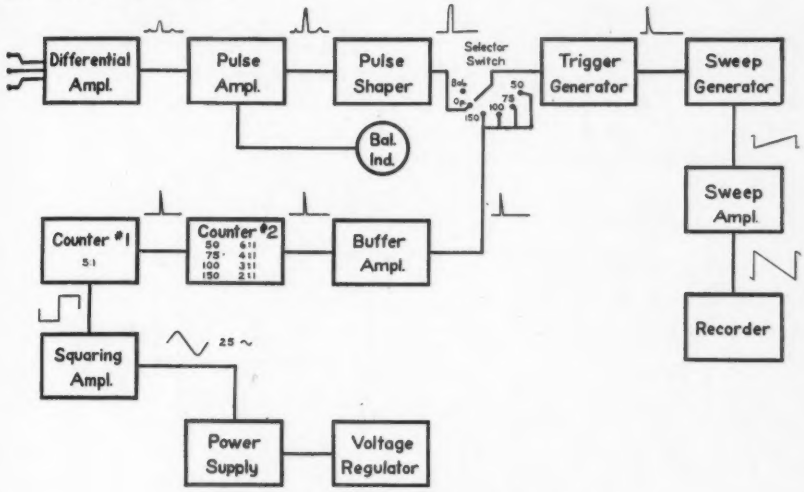

FIG. 1. *Cardiochronograph—Block diagram.*

The "pulse amplifier" provides two more stages of amplification. The second of these contains a gain control which permits adjustment for differences in cardiac voltage of individual subjects.

The voltage output from the pulse amplifier is fed into a "pulse shaper." Here the Q.R.S. complex of the cardiac potential is amplified further and distorted to give a sharp trigger pulse for the trigger generator. This consists of a thyratron which is normally extinguished. The arrival of a trigger pulse causes the tube to strike, thereby discharging the charged condenser in its plate circuit. In this manner a trigger pulse of constant amplitude and duration is produced coincident with each heart beat. This trigger pulse is used to control the action of the "sweep generator."

The sweep generator uses another thyratron to discharge a slowly charging sweep condenser at the instant a trigger pulse is received. Upon completion of the discharging of the condenser, the thyratron extinguishes, and the condenser again begins to charge, and is once again interrupted in its charging process by the succeeding pulse from the trigger generator, long before it reaches its full charge.

The series of saw-teeth of irregular amplitude as produced by the sweep generator is applied to the sweep amplifier. This stage is essentially a bridge circuit with a 5 ma. recording meter in the balance arm of the bridge. The

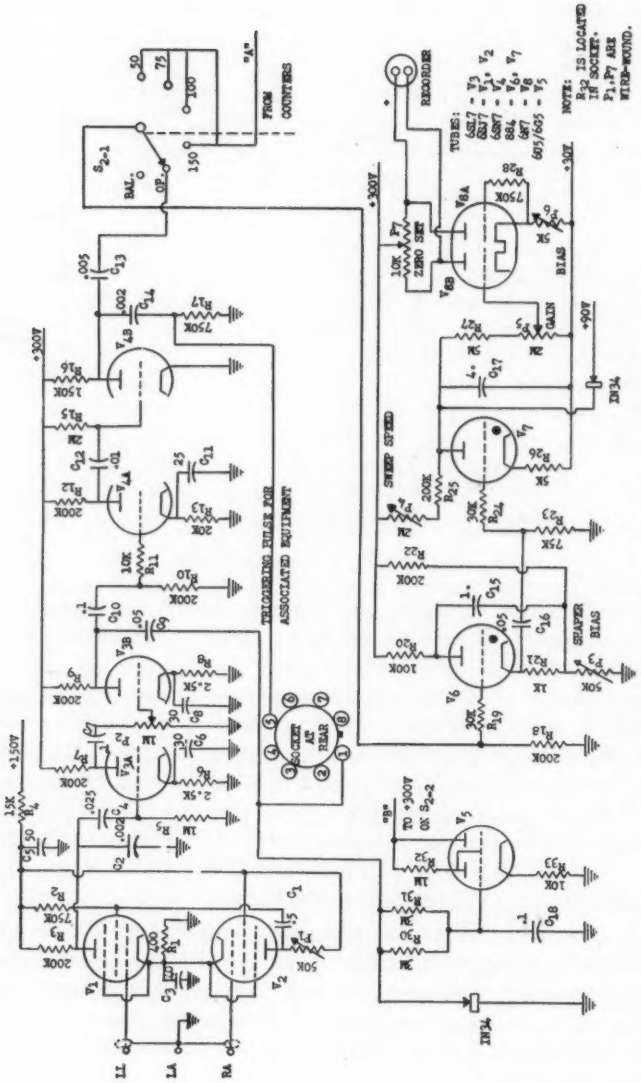

FIG. 2. *Cardiochronograph—Amplifiers and sweep circuits.*

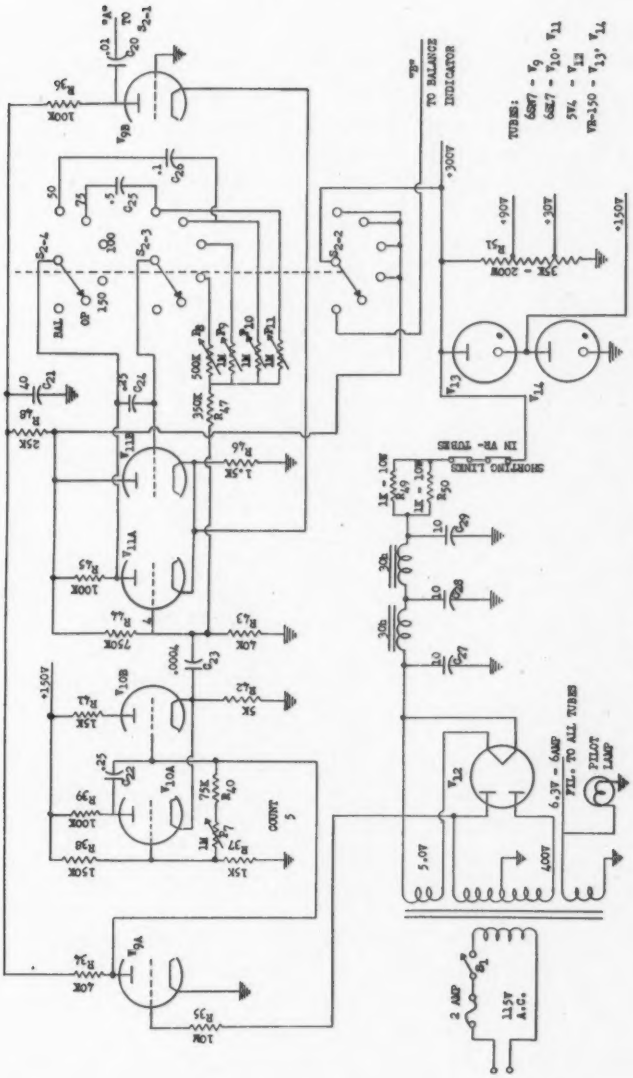

FIG. 3. *Cardiochronograph power supply and counters.*

series of saw-teeth is recorded on a slowly moving strip of paper so that each saw-tooth appears as a spike.

Summarizing briefly, we find the recording arm moving from zero towards full deflection. A heart beat is received, and the arm is immediately sent back to zero from where it once again starts sweeping towards full deflection. Another pulse sends it back to zero, and so forth. The length of the traces on the paper is therefore a measure of the period of successive heart beats (see Fig. 5).

Calibration circuits are provided for a convenient indication of the length of trace corresponding to different heart rates. Pulses at rates of 50, 75, 100, and 150 per min. are produced by the counters of the calibration circuits. The line frequency, which in this case happens to be 25 cycles per sec., is used to initiate the counters.

The power supply provides regulated d.c. at 300 and 150 v. for the operation of the circuits of the cardiochronograph.

Circuit Detail

Differential Amplifier

This consists of two type 6SJ7 pentodes. V_1 is a normal amplifier tube whose screen grid is coupled to the anode V_2. The balance control P_1, is adjusted so that the gain of V_2 plus the screen grid to plate gain of V_1 is equal to the control grid to plate gain of V_1. Thus if equal in-phase voltages are impressed on the control grids of V_1 and V_2, the effect on the output of V_1 is negligible, since the voltage applied to the screen of V_1 just neutralizes the effect of the voltage applied to its control grid. In this way, a rejection ratio of better than 500 to 1 is realized, and no screening of the subject from stray pickup is necessary. Because of the high amplification necessary in this equipment, it is advisable to insulate the sockets of these two tubes with soft rubber, thereby minimizing the electrical effects produced by mechanical vibration.

Pulse Amplifier

This consists of the two halves of a 6SL7, a high-gain double triode. A gain control, P_2, is provided in the input of the second half of this tube. The total gain of the amplifier circuits is approximately 100,000 maximum.

Pulse Shaper

A type 6SN7 medium-gain double triode is used in the pulse-shaper stage. Its purpose is to amplify and distort the Q.R.S. complex so that a steep-fronted trigger pulse is obtained (see Fig. 1). V_{4a} is normally biased to beyond cutoff. This insures that the P and T waves of the cardiac potentials, as well as any minor muscle action potentials, do not pass through the amplifier. Furthermore, the top of the Q.R.S. complex is clipped off owing to grid current flowing. Thus a fairly broad, negative-going square wave is passed into V_{4b}. This second triode, which on no-signal conducts at saturation, inverts and peaks the square wave. The resulting positive-going trigger pulse is brought over to the trigger generator at the "operate" position of the selector switch.

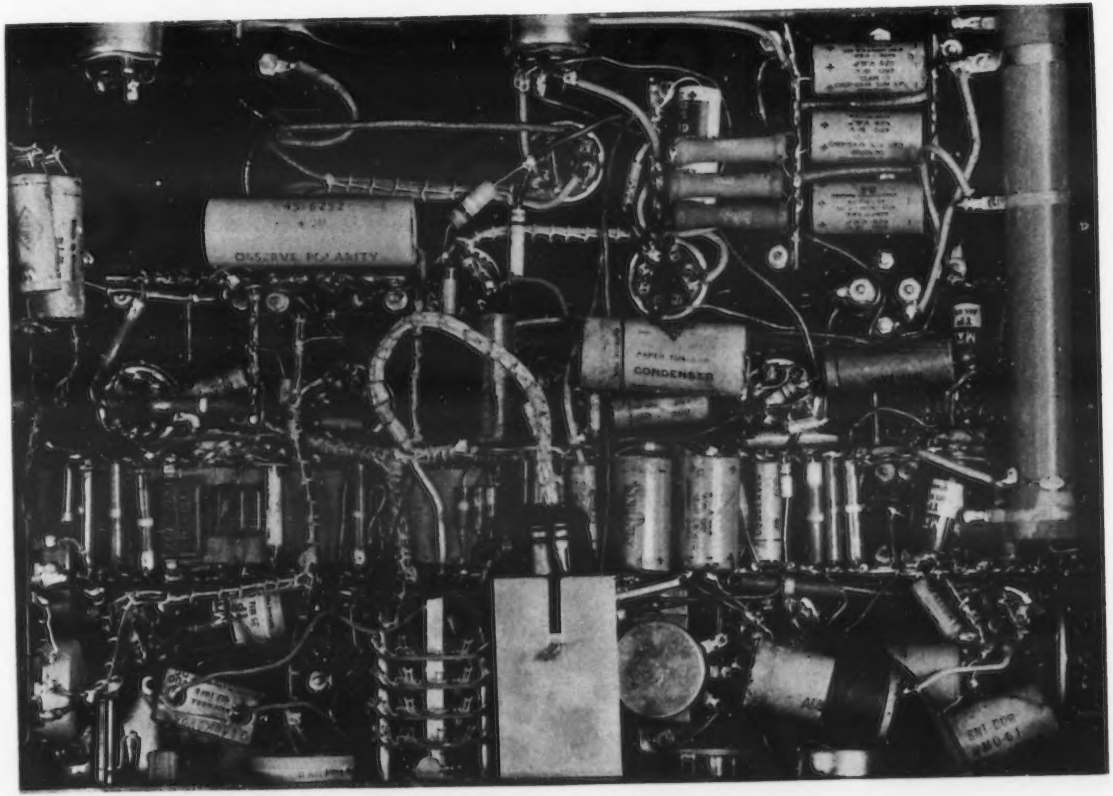

FIG. 4. *Bottom view of cardiochronograph.*

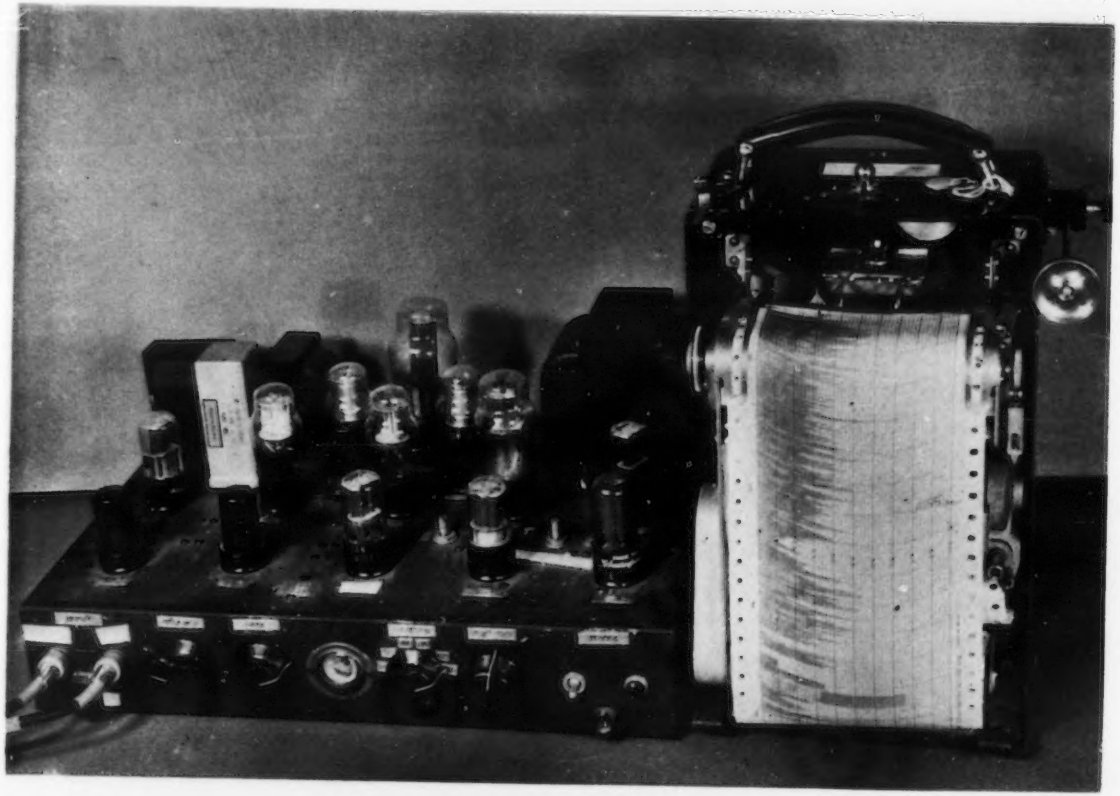

FIG. 5. *Complete apparatus (with covers removed).*

Balance Indicator

The output of the pulse amplifier is at all times fed into a type 1N34 crystal rectifier, associated with a "magic-eye" indicator tube, V_5. This crystal rectifies any a-c. component in the amplifier output and the resultant d.c., whose magnitude is proportional to the a-c. in-phase and unwanted component, is applied to the control grid of V_5.

With zero voltage on the grid, the bias has been set by R_{33} so that the eye is almost closed. Application of positive d-c. voltage from the crystal, via the smoothing filter, causes the eye to open. Thus, if the balance control, P_1, is properly adjusted for no in-phase voltages leaving the differential amplifier, the eye will be at minimum opening. The H.T. for V_5 is switched on by section 2 of the selector switch when in the balance position only. Thus the eye is illuminated only in this position. (Experience with the instrument has led us to prefer that the balance control should be omitted from the front panel and "pre-set," while the "magic-eye" would be retained to indicate the magnitude of the cardiac impulses coming through.)

Trigger Generator

This circuit employs a type 884 gas triode or thyratron, V_6. For every trigger pulse received by this tube, a pulse of constant amplitude and shape is delivered at the cathode output owing to the discharging of C_{15} through the tube. This trigger pulse retains its constancy regardless of the nature of the triggering pulse applied to the grid of the tube. A pre-set "shaper bias" control, P_3, is used in the cathode circuit of this tube to permit accurate adjustment of the bias.

Sweep Generator

The sweep generator, V_7, also uses an 884 thyratron. By means of an adjustable slider on the voltage divider of the power supply, this tube is biased so that it remains extinguished with no signal on the grid. In this case, 30 v. is a satisfactory bias. The trigger pulse causes the thyratron to 'strike' and discharge C_{17} in the plate circuit. As soon as the plate-to-cathode potential drops to the extinction value (about 18 v.), V_7 ceases to conduct and C_{17} begins to charge exponentially through the plate-load resistors. The rate of charge is controlled by P_4, the pre-set sweep-speed control. The charging condenser voltage is applied across R_{27} and the gain control, P_5. From the latter control, a reduced saw-tooth voltage is applied to the sweep amplifier.

When no trigger pulses are received at the grid of the sweep generator, the condenser C_{17} would charge up to 270 v. Since the sweep amplifier is directly coupled, a voltage of such magnitude would overload it and cause the needle of the recorder to remain hard over at maximum deflection. To prevent this, a 1N34 crystal unit is placed in the plate circuit of V_7 to act as a voltage limiter. The negative end of the crystal is attached to a slider on the voltage divider bleeder. The latter is adjusted so that the recorder needle will rest at slightly under maximum deflection when no trigger pulse is applied to the

sweep generator (for example, when the selector switch is in the balance position). This limiting voltage is approximately 90 v.

Sweep Amplifier

The sweep amplifier circuit is actually a bridge circuit wherein each triode section of a 6N7 forms a branch of the bridge. The two remaining branches are made up of the adjustable plate resistors, formed by P_7, the zero-set control. This control is located on the front panel of the instrument and is used to set the "75 pulses per minute" calibration sweeps coincident with the center ruling on the recording tape.

The pre-set bias control, P_6, adjusts the operating point on the "grid base" of the triode V_{8b} which serves as the "active" branch of the bridge network. It thus serves as a linearity control for the sweep.

Ink-recorder

A 0-5 ma. Easterline-Angus ink-writing recorder is used (Fig. 5). This meter had to be modified for rapid writing, because the instrument, as designed, is overdamped. This is because the moving coil is wound on a copper former made of a strip whose ends are soldered together under the winding. This junction was carefully opened without disturbing the coil, and transformer fishcloth was inserted between the ends, insulating them from one another. The assembly was glued back together with radio cement. The required amount of damping was found to exist when two $\frac{3}{4}$ in. lengths of No. 18 B & S copper wire, in parallel, were soldered across the junction.

Another modification of a minor nature consisted of attaching a solid rubber covered metal stop at the zero end of the recording needle in place of the flexible wire stop used on the instrument. This prevents excessive bounce on the needle fly-back. It was also found best to adjust the zero set of the instrument so that the needle rests at approximately mid-scale when no current is passed through it.

When operating, the recorder is made to travel at the "rapid feed" position, and the timing lever is adjusted for a feed of one transverse division of the recording paper per half minute.

A manometric recorder to write a record (on the same moving paper) of the depth and rate of respiration has also been mounted in the instrument.

Calibrator Circuits

These circuits consist of a squaring amplifier, two counters, and a buffer amplifier. Refer to the block diagram, Fig. 1.

Squaring Amplifier

One-half of a 6SN7, V_{9a}, is used to square a 400 v. (R.M.S.) sine wave, taken from the secondary winding of the 25 cycle power transformer. The resultant square-wave at the anode is differentiated in the coupling network, and the positive-going peak is used to trigger the first counter.

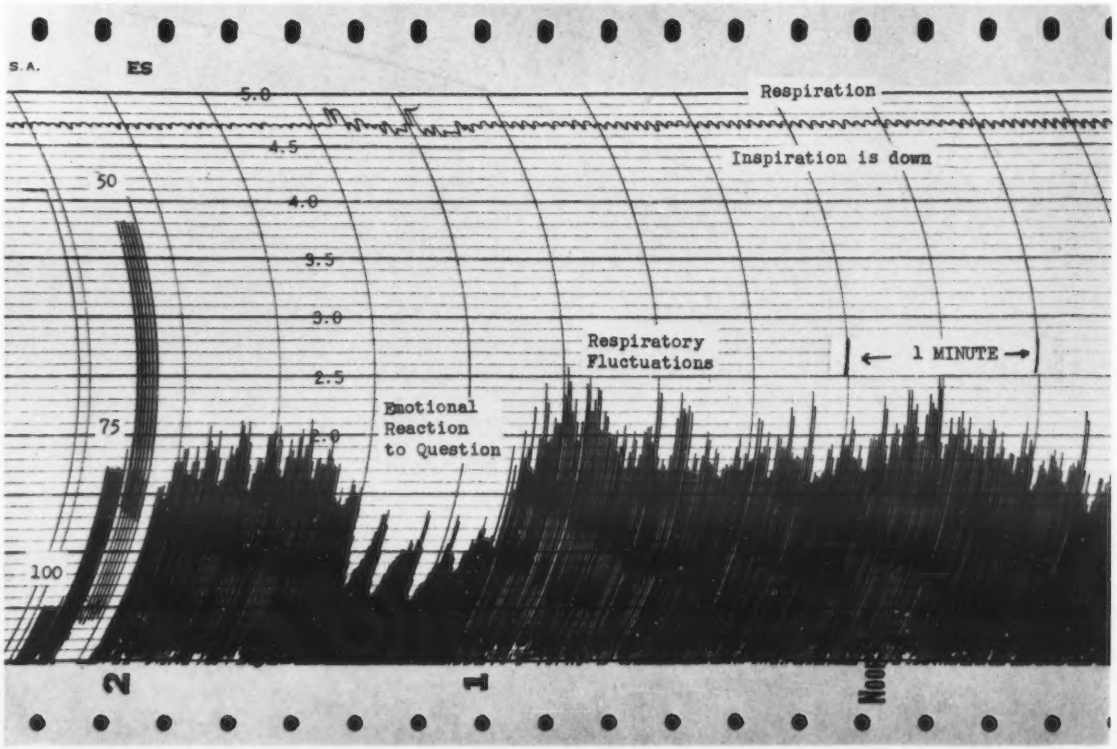

FIG. 6. *Record of normal subject, to be read from right to left. The calibration is shown on the extreme left-hand side.*

First Counter

The first counter, V_{10}, is a cathode-coupled multivibrator using both triodes of a 6SL7. Its natural frequency is approximately two cycles per second. By adjusting P_7, every fifth peak from the squaring amplifier is made to trigger the multivibrator before its natural time, thereby setting its frequency at 5 cycles per sec., or 300 cycles per min.

The cathode of this multivibrator is coupled to the second counter through a differentiating CR.

Second Counter

The second counter is also a cathode-coupled multivibrator. Two sections of the selector switch permit a change of coupling time constants to provide frequency rates of 50, 75, 100, and 150 cycles per min. (that is, counts of 6, 4, 3, and 2 respectively). The cathode circuit of this multivibrator is also the cathode circuit of the buffer amplifier, which is of the grounded-grid variety. The positive-going output is applied to the trigger generator at the "calibrate" positions of the selector switch, section 1.

Power Supply

The power supply uses a transformer supplying 800 v., center-tapped, for rectification. The d-c. output is regulated against line voltage surges by means of a pair of VR-150's, in series. A wire-wound bleeder with adjustable taps provides the necessary voltages for the sweep circuits, as described earlier.

The transformer also contains a secondary winding supplying 6.3 v. at 6 amp. for heater current.

Action of the selector switch supplies 300 v. d.c. to the "magic-eye" in the "balance" position, and to the counter circuits in the "calibrate" positions. These circuits are left without plate supply voltages in the "operate" position.

Results with the Instrument

The cardiochronograph has been in operation in research on the activity of the autonomic nervous system at the Medical School, University of Western Ontario, since February, 1947. This paper is not the place for any full account of results. A record of the heart rate and respiration of a normal subject, after lying quietly for 10 min., is shown in Fig. 6. It reveals, first, the unexpected degree of variability of heart period from beat to beat that is normally present. Such a variability would be quite unsuspected were it not for the cardiochronograph. In addition, rhythmic changes correlated with the respiration, and other cardiac accelerations and slowings not so related, are seen. The pattern of these changes is giving valuable information as to the activity of the nerves to which they are due. A simultaneous ink-writer record of the activity of the sweat glands, obtained by amplification of the bioelectric potential changes that occur, gives additional information. Details of this amplifier (the Electrical Sudograph) will be given in a separate paper.

References

1. BOAS, E. P. Arch. Internal Med. 41 : 403-414. 1928.
2. FLEISCH, A. Z. ges. exptl. Med. 72 : 384-400. 1930.
3. WHITE, B. V. and GILDEA, E. F. Arch. Neurol. Psychiat. 38 : 964-984. 1937.
4. WHITEHORN, J. C., KAUFMAN, M. R., and THOMAS, J. M. Arch. Neurol. Psychiat. 33 : 712-731. 1935.

AN OMNIDIRECTIONAL, VERTICALLY POLARIZED, FOUR ELEMENT ANTENNA ARRAY[1]

By R. S. Rettie[2]

Abstract

An omnidirectional, vertically polarized antenna was required for use in the ground installations of the Airborne Distance Indicator program of the National Research Council. This antenna was to be mounted on the center tower of the Radio Range Beacons of the Department of Transport, and it was hoped that a certain amount of gain over a quarter-wave rod antenna could be realized. This paper describes an array of four elements stacked vertically, each element being a half-wave radiator in the form of a cylinder surrounding a mounting pipe. A gain of about four decibels over a half-wave dipole is obtained in a rugged and relatively simple form. Operation is possible over a 10% frequency band, centered on 223 Mc. per sec. It is suggested that similar antennas may find a wide field of application in the VHF band.

The Required Antenna

In many forms of radio communication, the antenna is designed to give nondirectional coverage in the horizontal plane together with the highest possible field strength on the horizon. This is a general problem in broadcasting and in mobile services on all wave lengths. On long and medium wave lengths such performance is obtained by the use of high towers and special current distributions. On shorter wave lengths it becomes practical to stack several radiators one above another. Such radiators are usually omnidirectional and are fed in such a way that their fields reinforce on the horizon and cancel at high angles. Such antenna arrays are typified by the turnstile antennas of G. H. Brown, in both horizontally and vertically polarized forms (1).

In the Airborne Distance Indicator program of the National Research Council of Canada, a ground antenna was needed which would be vertically polarized and omnidirectional, have a useful gain over a quarter-wave rod and ground plane antenna, and be capable of simultaneous operation on two frequencies in the band 215 to 230 Mc. per sec. It was desired to mount this antenna on top of the 125-ft. central tower of the Canadian Department of Transport Radio Range Beaons, and, as a result, it had to be self-supporting, robust, and if possible, totally enclosed in a weatherproof sheath. An over-all length of 10 to 12 ft. (about two wave lengths) was indicated as a useful size. Thus the problem was to design a group of four half-wave dipoles, or two full-wave dipoles arranged in line vertically. Such an antenna would give a gain of the order of 4 db. over a half-wave dipole, and somewhat more over a quarter-wave rod and a small ground plane.

[1] *Manuscript received in original form March 4, 1948, and, as revised, July 5, 1948.*

Contribution from the Radio and Electrical Engineering Division, National Research Laboratories, Ottawa, Canada. Issued as N.R.C. No. 1815.

[2] *Formerly of the Radio & Electrical Engineering Division, National Research Council of Canada. Now at Clarendon Laboratory, Oxford, England.*

Possible Arrangements

The dipoles of such an array can be arranged either in series or in parallel. In the series form, usually called a collinear array, the antenna is fed at one end, and each element transfers power to the next through a phase-reversing section. This method was rejected because phase errors in these reversing sections are cumulative at other than the design frequency, and a severe limitation of the operating band results. In addition, such sectionalized antennas tend to be structurally weak.

In the parallel method of feeding, it is necessary to run the feed lines and a mounting pipe past some of the radiating elements. If this is done externally, serious interference with the radiators results unless the distance between the feed line and the radiators is large (at least one-half wave length); or unless a symmetrical arrangement of several radiators replaces the usual single radiator (1)—both clumsy and weak solutions of the problem. A natural development is to place the mounting pipe inside rather large radiators and to have the feed line inside the mounting pipe. Unwanted currents on the pipe cause no undesired directive effects in the horizontal plane, and the effect of these currents on the vertical directive characteristics and on the antenna impedance can be reduced by suitable methods of impeding their flow. Such antennas had been constructed previously at a wave length of 10 cm. using very fat dipole cylinders of radius about one-eighth wave length greater than that of the mounting pipe (3).

The Selected Design

It was decided to investigate the properties of an antenna similar to this last type, but having dipoles only slightly larger than the mounting pipe, the fact that this closer spacing would increase the currents induced on the mounting pipe being accepted. The effects of these currents are greatest near the ends of the pipe, especially the lower end where the terminating conditions are difficult to control. At the top end, the mounting pipe can be cut off at that distance found to be most useful in reducing the effects. A method of control at the bottom is to place a high impedance in the path of such currents. A quarter-wave choke, concentric with the mounting pipe, is very suitable for the purpose and its position is easily determined experimentally. The top of the antenna, as well as the bottom, can be fitted with such a choke, to provide flexibility in mounting other antennas, lighting fixtures, etc., above this antenna.

In the proposed antenna the radiators are four cylinders of sheet brass mounted on bakelite disks. The quarter-wave chokes are similar, but would have a metal disk short-circuited to the pipe at their remote ends. It appeared preferable to connect the radiators as full wave dipoles in order to simplify the feed arrangement and the matching problem. Two full wave dipoles in parallel would give an impedance of the order of 100 ohms (for the anticipated length-to-diameter ratio), while four half-wave dipoles in parallel would give

perhaps 20 ohms. The intended use of a shielded, balanced, two wire line inside the mounting pipe favored the use of higher impedances.

In order to realize a pure resistance load, the radiators were made somewhat shorter than a half-wave long, and, with the feed points a full wave apart, there are consequently large gaps between the radiators. The actual spacings were made larger at the ends of the dipoles than at the feed points, since short and direct connections at the feed points were considered more important than equal radiator spacing.

Space was allowed in the base of the antenna for a balance-to-unbalance coupler (2) between the main feeder of flexible concentric cable and the more convenient balanced two wire line inside the antenna itself. Two methods of connecting the dipoles were available. The lower dipole could be tapped off the line running to the upper, although this would introduce certain variations of phase with frequency which might be objectionable in very wide-band operation. The alternative, with some extra complication, would be to run equal length feeders to the two dipoles from a branch point midway between them, the dipoles thus being kept in phase for all frequencies. The latter method was considered unnecessarily complex for an experimental antenna as described below.

Such an antenna can be totally enclosed in a plastic sheath and would then, in this example, resemble a pole 12 ft. long and $4\frac{1}{2}$ in. in diameter. If desired, a heater can be placed below the lower choke and a stream of warm air passed through holes in the various disks in order to reduce icing troubles.

The Experimental Antenna

An antenna was designed for a mean frequency of 223 Mc. per sec., the general plan outlined above (see Fig. 1) being followed. The mounting pipe was steel, $2\frac{1}{2}$ in. in diameter and 12 ft., 9 in. long. With a $\frac{1}{4}$ in. wall thickness, it formed an exceedingly strong structure. The radiators and chokes were cylinders of sheet brass, 22 in. and $13\frac{1}{2}$ in. long, respectively, and each 4 in. in diameter. The radiators were spaced $\frac{7}{8}$ in. apart at the dipole feed points, and 8 in. apart between the dipoles. The chokes were spaced $8\frac{1}{2}$ in. from the dipoles, as determined experimentally.

Each dipole was connected by $\frac{1}{2}$ in. diameter brass rods, $1\frac{5}{8}$ in. long, to a balanced transmission line of characteristic impedance equal to 185 ohms. Just below the feed point of the lower dipole, the line impedance changed from 185 to 96 ohms, and a quarter-wave transformer of 73 ohms impedance in the correct position served to match the two impedances. The balance-to-unbalance coupler at the base of the antenna consisted of a shielded parallel-conductor, quarter-wave stub, with the concentric feed line running inside one arm. At the same time this coupler incorporated a transformer to match the 96 ohm, two conductor line to the 50 ohm concentric feed line. Fig. 1 is a schematic drawing.

The Experimental Results

In order to investigate the free space vertical radiation pattern, the antenna was placed on its side and rotated in the horizontal plane. When the chokes

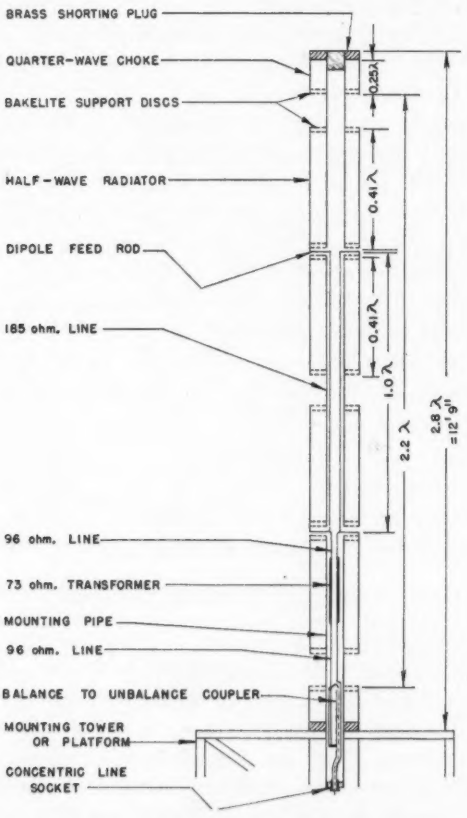

FIG. 1. *The schematic diagram of the experimental antenna.*

had been positioned for minimum side lobes the results shown in Fig. 2 were obtained at 223 Mc. per sec. Included for comparison in Fig. 2 is part of a theoretical pattern for four half-wave dipoles, spaced equally at half-wave distances, and fed in the same phase and amplitude. The larger side lobes in the experimental case are due to unwanted current still present, but are unimportant in the present application except for a minor decrease in gain. The true horizontal pattern is circular and thus the free space pattern is disk-shaped. The true vertical pattern should include the effect of ground reflection, but, owing to the high elevation of this antenna, the lobe structure

is fine, and in practice is not noticeable. The effect of the ground is then merely to cut off the radiation at angles below and very near to the radio horizon.

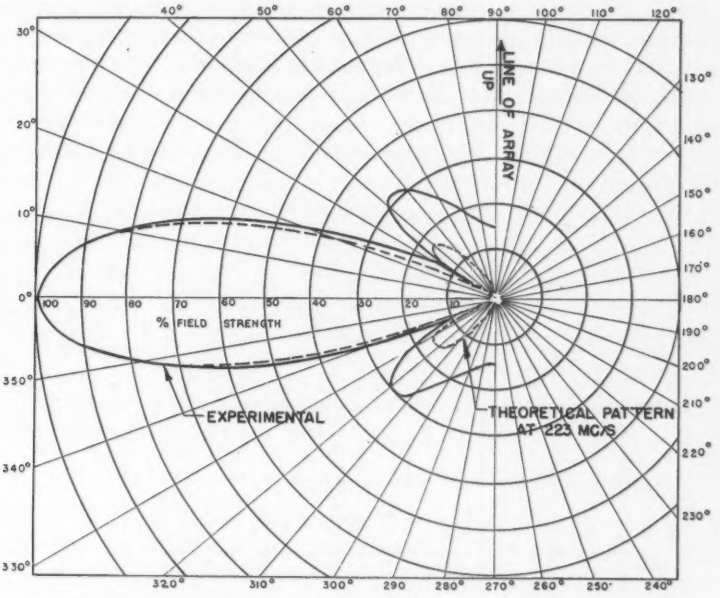

FIG. 2. *The free-space vertical radiation pattern at 223 Mc. per sec.*

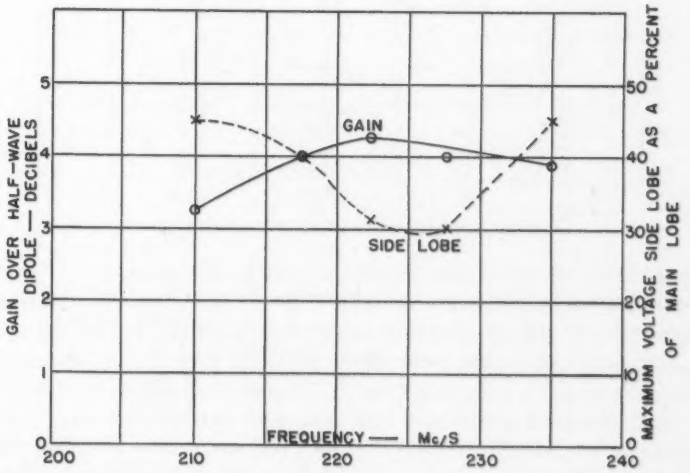

FIG. 3. *The antenna gain and the maximum amplitude of side lobes plotted against frequency.*

The gain of the antenna, as calculated from these patterns is 6.3 db. over an isotropic radiator, or 4.2 db. over a very short dipole. The theoretical gain calculated from the theoretical patterns is 6.5 db. over an isotropic radiator. The gain at other frequencies is illustrated in Fig. 3, together with the variation of side lobes with frequency. An improved gain at 210 Mc. per sec. could be secured easily with little loss at 235 Mc. per sec. by increasing the dipole spacing and using a branched feeder as mentioned in "The Selected Design" above. The width of the vertical radiation pattern at half voltage points decreases steadily from 36 degrees at 210 Mc. per sec., to 31 degrees at 235 Mc. per sec.

For this application, in common with many others, the directive characteristics and the gain are not as important as the impedance variations of the antenna. The degree of antenna mismatch may be expressed as a voltage standing wave ratio in the transmission line. From this the range of impedances presented to the transmitter may be found readily, and excess line losses, reflection losses, etc., calculated.

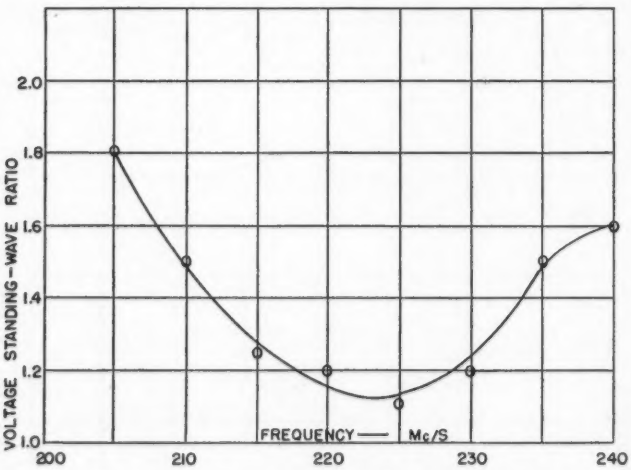

FIG. 4. *The antenna match plotted against frequency.*

Fig. 4 shows the variation of antenna match with frequency. Thus for a voltage standing wave ratio less than 1.2, we have about a 5% frequency band, and for a voltage standing wave ratio less than 1.5 we have a 10% band. It was not considered worth while to attempt to improve these results, although it was known that the dipoles were somewhat too short for resonance, and good broadband technique demands correction of each error as closely as possible to its source. However, the results obtained with this experimental arrangement point out the ease with which this type of antenna can be matched over a broad band of frequencies.

Further Possibilities

It is felt that this design of an omnidirectional, vertically polarized, antenna array could be adapted for use on wave lengths up to 10 m. and down to 10 cm. One or more pairs of half-wave dipoles could be connected up in this fashion. Perhaps the most useful form of this antenna would be one consisting of a single pair of half-wave dipoles, for frequency modulated broadcasting, television, or mobile services, which are generally at wave lengths of a few meters. A gain of nearly 3 db. over a half-wave dipole could be expected in a fairly simple structure.

The method of feeding the radiators in arrays of this type can be modified easily to suit individual requirements. For example, a concentric line may be continued on up the mounting pipe internally or even externally, and either lumped or distributed constant balancers used at the dipole feed points. Other methods of impeding the current induced on the mounting pipe are also available and may be applied in certain cases. One obvious method is to cut off the pipe near the position of the top choke. Again a suitable ground plane may be available, and it can be placed a quarter-wave below the mouth of the lower choke, which may then be omitted. It is felt, however, that the antenna described here is the most flexible arrangement to apply to problems where vertical polarization is required in the VHF band.

References

1. BROWN, G. H. Electronics, 9 : 14-17 and 48. April. 1936.
2. MARCHAND, N. Electronics, 19 : 142-145. December. 1944.
3. RIBLEY, H. J. Radiation Laboratory Report No. 623.